

**EVALUATION OF PALM KERNEL SHELL ASH AS AN ADDITIVE FOR  
THE STABILIZATION OF BLACK COTTON SOIL**

**BY**

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**ZARIA, NIGERIA**

**OCTOBER, 2018**

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**DEPARTMENT OF CIVIL ENGINEERING,  
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ZARIA, NIGERIA**

**OCTOBER, 2018**

## DECLARATION

I declare that the work in this dissertation entitled “**Evaluation of Palm Kernel Shell Ash as an Additive for the Stabilization of Black Cotton Soil**” has been carried out by me in the Department of Civil Engineering, Ahmadu Bello University Zaria. The information derived from the literature has been duly acknowledged in the text and a list of references provided .No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

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Signature

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## CERTIFICATION

This Dissertation titled “**Evaluation of Palm Kernel Shell Ash as an Additive for the stabilization of Black Cotton Soil**” by Oluwatudimu; Oladipo Emmanuel meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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## **DEDICATION**

With sincere thanks and profound gratitude, I wish to dedicate this research to God Almighty, the giver of life.

## ACKNOWLEDGEMENTS

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## ABSTRACT

Black cotton soil (BCS) obtained from Baure; Yamaltu Deba Local Government Area was treated with up to 12 % palm kernel shell ash (PKSA) by weight of dry soil to determine the suitability of the treated soil for use in road construction. Index tests were carried out to classify the natural soil, while the moisture-density relationships were determined by compaction tests on the natural and treated soils using three energy levels viz, British Standard light (BSL), West African Standard (WAS) and British Standard heavy (BSH). Black Cotton Soil used in the study was classified as A-7-5 (20) using the American Association of State Highway and Transportation Officials (AASHTO) and CH group in the Unified Soil Classification System (USCS). Tests results show that specific gravity of the soil increased from 2.29 for the natural to 2.34 at 12 % treatment. Liquid limit decreased from 76.2 % for natural to 73.4 % at 10 % PKSA content. Plastic limit increased from 40 % for the natural soil to 47.1 % at 12 % PKSA content treatment. Maximum dry density (MDD) values decreased from 1.44 Mg/m<sup>3</sup>, 1.5Mg/m<sup>3</sup> and 1.65 Mg/m<sup>3</sup> for the natural soil to 1.38 Mg/m<sup>3</sup> at 10 %, 1.45 Mg/m<sup>3</sup> at 10 % and 1.56 Mg/m<sup>3</sup> at 6 % PKSA content for BSL, WAS and BSH compaction energy levels, respectively. On the other hand, optimum moisture content (OMC) value decreased from 28.5 % and 22.4 % for the natural soil to 22.4 % and 21.0 % at 12 % PKSA content for BSL and WAS energies, respectively, while the value for BSH energy increased from 18.2 % to 19.0 % at 8 % PKSA content. Peak 7 days unconfined compressive strength (UCS) values of 351.59, 362.64 and 539.17 kN/m<sup>2</sup> at 8 % PKSA content were recorded for BSL, WAS and BSH compactive efforts, respectively. The peak unsoaked California bearing ratio (CBR) values of 10, 15 and 27 % as well as soaked CBR values of 3, 3 and 7 % at 10 % PKSA were obtained for BSL, WAS and BSH compactions, respectively. Peak durability (resistance to loss in strength) values of 17.6 % (i.e., 82.4 % loss in strength), 14.1 % (i.e., 85.9 % loss in strength) and 11.9 % (i.e., 88.1 % loss in strength) were recorded for specimens compacted with BSL, WAS and BSH energies, respectively. Results obtained show that 8 % PKSA treatment of BCS improved the strength characteristics of BCS, but it can only be used as a subgrade material in road construction. The benefit of the technique includes the elimination of the negative impact of PKSA on the environment

## TABLE OF CONTENTS

COVER PAGE	i
TITLE PAGE	ii
CERTIFICATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
TABLE OF CONTENTS	vii
LIST OF TABLE	xiii
LIST OF FIGURES	xvi
LIST OF PLATES	xviii
INTRODUCTION	1
1.1 Preamble	1
1.2 Statement of Research Problem	3
1.3 Justification for the Study	4
1.4 Aim and Objectives of the Study	4
1.5 Scope of the Study	5
CHAPTER TWO	6
LITERATURE REVIEW	6
2.1 Origin and Formation of Black Cotton Soil	6
2.1.1 Physical weathering of rocks	7

2.1.2	Chemical weathering of rocks	8
2.2	Description of Black Cotton Soil	8
2.2.1	The characteristics of black cotton soils	8
2.2.2	Mineralogical Properties of Black Cotton Soil	9
2.2.3	Chemical and clay mineralogical status of black cotton soils	10
2.3	Soil Stabilization	11
2.3.1	Mechanical stabilization	12
2.3.2	Chemical stabilization	13
2.3.3	Stabilization of Expansive Soil Using Industrial Solid Wastes	13
2.3.3.1	Fly Ash	13
2.3.3.2	Blast Furnace Slag and Cement	14
2.3.3.3	Admixtures	14
2.3.3.4	Cement Kiln Dust	15
2.3.3.5	Stabilization of Expansive Soil using Agricultural Solid Wastes	15
2.3.3.6	Groundnut Shell Ash	15
2.3.3.7	Portland cement - Locust Bean Waste Ash Blend	16
2.3.3.8	Stabilization of Expansive Soil using Mineral Solid Wastes	16
2.3.3.9	Marble Powder	16
2.4	Palm Kernel Shell Ash (PKSA)	17
	CHAPTER THREE	20
	MATERIALS AND METHODS	20

3.1	Materials	20
3.1.1	Black cotton soil	20
3.1.3	Water	21
3.2	Methods	21
3.2.1	Natural Moisture Content	22
3.2.2	Particle Size Distribution Analysis	22
3.2.2.1	Wet sieving	22
3.2.2.2	Dry sieving	23
3.2.3	Atterberg Limits	24
3.2.3.1	Liquid limit	24
3.2.3.3	Plasticity Index	25
3.2.4	Free Swell	26
3.2.5	Compaction Characteristics	27
3.2.5.1	Maximum dry density	27
3.2.5.2	Optimum moisture content	28
3.2.6	Strength Parameters	28
3.2.6.1	Unconfined compressive strength	28
3.2.6.2	Durability assessment (Resistance to Loss in strength)	29
3.2.7	California Bearing Ratio	30
3.2.8	Cation Exchange Capacity	31
3.2.9	Specific Gravity	32
3.2.10	Microanalysis	34

3.2.11 Analysis	
334	
3.3.11.1 Graphical method using Microsoft Excel software package.	34
3.3.11.2 Statistical Analysis using Microsoft Excel software package.	34
3.3.11.3 Regression Analysis using Microsoft Excel software package (XLSTA)	34
<b>RESULTS AND DISCUSSION</b>	<b>35</b>
4.1 Properties of the Material Used in the Study	35
4.1.1 The natural black cotton soil	35
4.1.2 Chemical compositions of the materials used in the study	37
4.2 Effect of Palm Kernel Shell Ash on the Properties of Black Cotton Soil	38
4.2.1 Specific gravity	38
4.2.3 Wet Sieving	42
4.2.4 Atterberg limits	44
4.2.5 Cation exchange capacity	45
4.2.6 Compaction characteristics	47
4.2.6.1 Maximum dry density	47
4.2.6.1.1 Regression Analysis for MDD	49
4.2.6.2 Optimum moisture content	51
4.2.7 Unconfined compressive strength `	53
4.2.7.1 7 days curing period	53
4.2.7.1.1 Model equation for UCS (7 days curing)	53
4.2.7.2 14 days curing period	55

4.2.7.3 28 days curing period	56
4.2.8 Effect of curing period on unconfined compressive strength	58
4.2.9 Durability	59
4.2.10 California Bearing Ratio	61
4.2.10.1 Unsoaked condition	61
4.2.10.1.1 Model equation for unsoaked CBR	62
4.2.10.2 Soaked	63
4.2.10.2.1 Model equation for soaked CBR	64
4.2.11 Microanalysis	65
4.2.11.1 7 days curing period	
685	4.2.11.2 28 days curing period
68	
CHAPTER FIVE	70
CONCLUSION AND RECOMMENDATION	70
5.1 Conclusion	70
5.2 Recommendation	72
REFERENCES	73
APPENDIX	79

## LIST OF TABLES

2.1: General Categorization Of Black Cotton Soil Of North–Eastern Nigeria	91
2.2: Oxides Composition Of Black Cotton Soils From Some Countries	11
2.3: Oxides Composition Of Palm Kernel Shell Ash	19
4.1a: Properties Of The Natural Black Cotton Soil	36
4.1b: Chemical Compositions Of Black Cotton Soil And Palm Kernel Shell Ash	38
4.2: One - Way Analysis Of Variance Result For Specific Gravity Of Black Cotton Soil – Palm Kernel Shell Ash Mixtures	39
4.5: One - Way Analysis Of Variance Result For Atterberg Limits Of Black Cotton Soil – Palm Kernel Shell Ash Mixtures	45
4.6: The One – Way Analysis Of Variance (Anova) Test On The Cation Exchange Capacity Of Black Cotton Soil – Palm Kernel Shell Ash Mixtures	47
4.7: One - Way Analysis Of Variance (Anova) Test On The Maximum Dry Density Of Black Cotton Soil – Palm Kernel Shell Ash Mixtures	50
4.8: One - Way Anova On The Effect Of Pksa On Optimum Moisture Contents Of BSL, WAS And BSH	52
4.9: One - Way Analysis Of Variance (Anova) For Unconfined Compressive Strength (7 Days Curing Period) On Black Cotton Soil – Palm Kernel Shell Ash Mixtures	54
4.10: One - Way Analysis Of Variance (Anova) For Unconfined Compressive Strength (14 Days Curing Period) On Black Cotton Soil – Palm Kernel Shell Ash Mixtures	56
4.11: One - Way Analysis Of Variance (Anova) For Unconfined Compressive Strength (28 Days Curing Period) On Black Cotton Soil – Palm Kernel Shell Ash Mixtures	58
4.12: One - Way Analysis Of Variance (Anova) Of The Unconfined Compressive Strength Of Black Cotton Soil - 8 % Palm Kernel Shell Ash Mixture	59
4.13: One - Way Analysis Of Variance (Anova) Test On The Durability Of Black Cotton Soil – Palm Kernel Shell Ash Mixtures.	61

4.14: The One Way Analysis Of Variance (Anova) Result Of Unsoaked Cbr Of Black Cotton Soil – Palm Kernel Shell Ash Mixtures	63
4.15: The One Way Analysis Of Variance (Anova) Result On The Soaked Cbr Of Black Cotton Soil – Palm Kernel Shell Ash Mixtures	65
A3.1: Values Of Effective Depth Based On Hydrometer And Sedimentation Cylinder of Specific Sizes	80
A3.2: Values of K Use In Equation For Computing Diameter of Particle in Hydrometer Analysis	81
A4.2i: Variation of Palm Kernel Shell Ash on Specific Gravity of the Soil Specimen	82
A4.2 ii: Specific Gravity of The Natural Soil	82
A4.3a: The Grain Size Distribution of Treated Black Cotton Soil Mixed at Optimum Moisture Content from British Standard Light Compaction	86
A4.3b: The Grain Size Distribution of Treated Black Cotton Soil at Optimum Moisture Content of West African Standard Compaction	87
A4.3c: The Grain Size Distribution of Treated Black Cotton Soil at Optimum Moisture Content of British Standard Heavy Compaction	88
A4.4a: The Variation of Grain Size Distribution on Black Cotton Soil in Hydrometer Analysis	89
A4.4b: The Variation of Palm Kernel Shell Ash on Soil Group/Texture Of Black Cotton Soil In Hydrometer Analysis	90
A4.5: The Variation of Pksa on Atterberg Limit of Baure Black Cotton Soil	90
Tablea4.6: The Effect of Pksa on Cation Exchange Capacity of The Baure Black Cotton Soil	91
A4. 7a: The Effect of Palm Kernel Shell Ash on Maximum Dry Density of the Baure Black Cotton Soil Compacted With BSL, WAS, And BSH	91
A4.7b: Model Parameters for MDD	92
A4.7c: Goodness Of Fit Statistics for MDD	93

A4.8a: The Variation of Palm Kernel Shell Ash on Optimum Moisture Content of the Baure Black Cotton Soil Compacted with BSL, WAS, And BSH	94
A4.8b: Model Parameters for OMC	94
A4.8c: Parameters For Goodness Of Fit Statistics for OMC	95
A4.9a: The Variation Of Palm Kernel Shell Ash On Unconfined Compressive Strength Of Baure Black Cotton Soil Compacted With Bsl, Was And Bsh Energies And Cured For 7 Days	96
A4.9b: Model Parameters For 7days Ucs	97
A4.9c: Goodness Of Fit Statistics For 7days Cured UCS	98
A4.10: The Variation Of Palm Kernel Shell Ash On Unconfined Compressive Strength Of Baure Black Cotton Soil Compacted With Bsl, Was And Bsh Energies And Cured For 14 Days	99
A4.11: The Variation Of Palm Kernel Shell Ash On Unconfined Compressive Strength of Baure Black Cotton Soil Compacted With Bsl, Was And Bsh Energies And Cured For 28 Days	99
A4.13: The Variation Of Pksa On Resistance To Loss In Strength Of The Soil Specimen	100
A4.14: The Variation Of Palm Kernel Shell Ash On Unsoaked Cbr (At 2.54mm Penetration) of Black Cotton Soil At Three Compactive Efforts	100
A4.15: The Variation Of Palm Kernel Shell Ash On Soaked Cbr (At 2.54mm Penetration) Of Black Cotton Soil At Three Compactive Efforts	101

## LIST OF FIGURES

4.1: Particle Size Distribution Curve of The Natural Black Cotton Soil	37
4.2: Variation Of Specific Gravity of Black Cotton Soil With Palm Kernel Shell Ash Content	39
4.3a: Particle Size Distribution Curves of Black Cotton Soil Palm Kernel Shell Ash Mixtures (BSL Compaction)	40
A4.3b: The Grain Size Distribution of Treated Black Cotton Soil at Optimum Moisture Content of West African Standard Compaction	41
A4.3c: The Grain Size Distribution of Treated Black Cotton Soil at Optimum Moisture Content Of British Standard Heavy Compaction	42
4.4a; The Variation Palm Kernel Shell on Particle Size Distribution Of Black Cotton Soil In Hydrometer Analysis	43
A4.4b: Variation of Black Cotton Soil Fraction With Palm Kernel Shell Ash Content During Hydrometer Analysis	43
4.5: Variation of Atterberg Limits of Black Cotton Soil With Palm Kernel Shell Ash Content	44
4.6: Variation of Cation Exchange Capacity of Black Cotton Soil With Palm Kernel Shell Ash Content	46
4.7: Variation Of Maximum Dry Density Of Black Cotton Soil With Palm Kernel Shell Ash Content	48
4.9: Variation Of Unconfined Compressive Strength (7 Days Curing Period) Of Black Cotton Soil With Palm Kernel Shell Ash Content	54
4.10: Variation Of Unconfined Compressive Strength (14 Days Curing Period) Of Black Cotton Soil With Palm Kernel Shell Ash Content	56
4.11: Variation Of Unconfined Compressive Strength (28 Days Curing Period) Of Black Cotton Soil With Palm Kernel Shell Ash Content	57
4.12: Variation of Peak Unconfined Compressive Strength of Black Cotton Soil - 8 % Palm Kernel Shell Ash Mixture With Curing Period	58
4.13: Variation of Resistance to Loss In Strength of Black Cotton Soil With Palm Kernel Shell Ash Content	61

4.14: Variation of Unsoaked California Bearing Ratio of Black Cotton Soil With Palm Kernel Shell Ash Content 63

4.15: Variation of soaked California Bearing Ratio of Black Cotton Soil With Palm Kernel Shell Ash Content 65

## LIST PLATES

1: Typical sheared palm kernel shells from oil palm fruit.	2
2: Map of the Baure in Yamaltu/Deba Local Government Area, Gombe State	20
I: Micrograph Of The Natural Black Cotton Soil Cured For7 Days at Magnification of X500 (BSL Compaction)	67
II: Micrograph Of Black Cotton Soil - 8% Palm Kernel Shell Ash Mixture Cured for 7 Days With Magnification Of X500 (BSL Compaction)	67
III: Micrograph of The Natural Black Cotton Soil Cured for 28 Days With Magnification of X500 (BSL Compaction)	69
IV. Micrograph of Black Cotton Soil - 8% Palm Kernel Shell Ash Mixture Cured for 28 Days with Magnification of X500 (BSL Compaction)	69

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Preamble

Expansive soils (also known as black cotton soils because the cotton plant thrives well on them) are major problematic soils of some tropical countries, especially in Africa and Asia. They are poor materials by temperate zone standards and difficult to use for road and air field construction because they swell due to the presence of large percentages of expansive clay minerals (i.e., montmorillonite).

Many roads and foundations of light buildings have been reported distressed due to the seasonal volume change (i.e., swell and shrinkage) of these soils, Chen, (1988). These soils swell when in contact with water and shrink on drying. The soil deposits are usually extensive making it impossible to avoid or by pass during construction of engineering projects. Expansive soils have reportedly inflicted billions of dollars in damages and repairs annually to earth structures and facilities, (Gidigasu and Gawu, 2013).

Black cotton soils possess low strength and undergo excessive volume changes, making their use in the constructions very difficult. The properties of the black cotton soils may be altered in many ways viz, mechanical, thermal, chemical and other means. Improvement of black cotton soils by chemical additives is a common stabilization method for such soils (Bell, 1993). Among various additives available lime, fly ash and cement are most widely and commonly used for the stabilization of the black cotton soils.

In Nigeria, black cotton soils are found predominantly in the North - Eastern region of the country, lying within the Chad Basin and partly within the Benue trough which occur over an area of 4 million hectares between latitudes 8° 30' and 12° 30' N and longitudes 10° and 14° E within the Savannah ecological zone of the country (Klinkenberg and Higgins, 1968).

In Nigeria it is believed that these soils derive their origin from Basalts of the upper Benue Trough which cover several hundred square kilometers, extending North and East of the Jos Plateau and from quaternary sediments of lacustrine origin, from the Chad Basin mainly consist of shale, clays and sandy sediments (Gidigas and Gawu, 2013).

Its wide coverage in the region makes it unavoidable during construction of roads and other facilities, hence the need to study the behaviour of the soil.

Palm kernel shells (Plate 1) are a waste product from the processing of oil fruits in palm oil mills. Oils are extracted from both the oil palm fruit mesocarp fibre (palm oil, edible oil) and the core (palm kernel oil which is used in the food and soap industry).

The palm kernel shell ash (i.e. the burnt sheared shell) has pozzolanic properties that enables it act as a partial replacement for cement and also plays an important role in the strength and durability of soil Ogbodo, (2017). Its use in the stabilization of soils will alleviate the increasing challenges of scarcity and high cost of cement.

The focus of this study is to evaluate the potency of palm kernel shell ash when used as a stabilizing additive of black cotton soil when used in road construction.



Plate 1: Typical sheared palm kernel shells from oil palm fruit.

## 1.2 Statement of Research Problem

Generally in the world, expansive soils are structurally “unstable” and “problematic” geo-materials which are sources of worry to engineers working with or on them. They are considered problematic mostly because they are characterized by unusual in-service behaviour, including such geo-environmental phenomena as heaving, swell, collapse, dispersion, erosion, excessive creep, subsidence and high compressibility, which render them poor construction materials (Gidigas, 2009 and Amir, 2016). Consequently, there is need for the improvement of geotechnical properties of the soils.

In the production of palm oil, the flesh is steamed and cooked. Palm kernel oil is extracted from the fruit core as the core is crimped and oil is released. For every 100 kg of fruit bunches, 22 kg palm oil and 1.6 kg palm kernel oil can typically be extracted. The sheared palm kernel shells are popular biofuel with high calorific value. For every 100 kg fruits around 4 kg palm kernel shells are left-over, (i.e. approximately 4%). Overall, palm kernel shells count for less than 1% of the total biomass in a palm oil plantation, (Otunyo *et al*, 2011).

Palm kernel wastes produced from small and medium-scale industries pose a serious environmental problem in Nigeria. A portion of these wastes is used as feed supplements for livestock, but most are disposed of by burning in the industry for heating purposes.

This practice is an environmental concern and the by-product ash is also a problem which needs to be addressed (Kolade *et al*, 2006). Alternative economic disposal methods are necessary and one potential method is to use the wastes as additives to improve soil properties.

This research will evaluate effect of palm kernel shell ash waste as an additive to improve black cotton soil.

### **1.3 Justification for the Study**

The over dependence on industrially manufactured soil improving additives (cement, lime and bitumen) has kept the cost of construction of stabilized roads high. This hitherto has continued to deter the under developed and poor nations of the world from providing accessible roads to meet the needs of the rural dwellers (who constitute large percentage of their population and are mostly rural farmers) of the regions covered by black cotton soil.

Furthermore, the World Bank has been expending substantial amount of money on research aimed at harnessing industrial waste products for further usage Oriola and Moses, (2010).

Palm kernel Shell ash and shell have the potential to be used as a partial replacement for cement and aggregate, respectively leading to reduction in the cost of construction, and a convenient means of waste disposal and resource preservation, Oti *et al.*, (2015).

Thus, the possible use of agricultural waste (such as Palm Kernel Shell Ash - PKSA) will considerably reduce the cost of construction and eliminate the environmental hazards caused by such a waste.

### **1.4 Aim and Objectives of the Study**

The aim of this research is to evaluate the suitability of palm kernel shell ash (PKSA) as a stabilizing agent for black cotton soils when used in road construction.

The specific objectives of the study include:

1. Determination of the physical properties of the natural and stabilized black cotton soil together with their oxide composition.
2. Determination of the moisture-density relationship of the natural and treated soil using three compactive efforts (i.e., British Standard light, BSL, West African Standard, WAS and British Standard heavy, BSH).

3. Determination of the strength properties (California bearing ratio, CBR and unconfined compressive strength, UCS) as well as the durability of the palm kernel shell ash treated black cotton soil.
4. Microanalysis of specimens of black cotton soil – palm kernel shell ash mixtures using scanning electron microscope (SEM).

### **1.5 Scope of the Study**

This study was limited to the use of palm kernel shell ash as an additive for stabilizing black cotton soil in road construction.

Test were carried out to determine the optimum quantity of palm kernel shell ash required for desired quality of the soil treated with palm kernel shell ash (PKSA) in stepped concentration of 2 % (i.e., 0, 2, 4, 6, 8 10, 12 and 14%) to improve the engineering properties of the soil.

All tests will be carried out in accordance with BS 1377 (1990) and BS 1924 (1990) for the natural and treated soils, respectively.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Origin and Formation of Black Cotton Soil

The geological process responsible for transformation of rock into soil is weathering. Weathering is a pedogenic process by which soils are formed as a result of disintegration or decomposition of rocks.

Chemical weathering causes changes in rocks at and near the earth's surface by interaction between the rocks and chemically active components of the earth's atmosphere, principally water, carbon dioxide and oxygen.

Within a given area on the earth's surface and at a given geologic time, the particular effects of weathering is assessed in terms of at least five variables: (1) climate, (2) biological activity, (3) topography, as this affects the movement of underground water, or contributes to erosional removal of weathered material (4) parent material (rocks) and (5) time.

There are three main processes of breaking down rock masses: (1) physical, (2) chemical, and (3) biological processes, Gidigas and Dogbey, (1980)

A physical process reduces particle size, increases surface area, and increases bulk volume. Chemical and biological processes may cause complete changes in physical, chemical and mineralogical composition of the end products. Robinson (1949) recognized two main stages in chemical weathering. The first stage is the destruction of mineral phases, and the second stage the formation of secondary products.

These two stages involve various processes which result in two main types of materials of morphogenic interest such as,

- (i) weathering residues and secondary materials which occur, and
- (ii) materials which are transported before deposition.

The first process of physical or mechanical weathering is also known as disintegration while the second process is decomposition. Disintegration results in a decrease in size of rocks and minerals without appreciably affecting their composition.

In the case of decomposition, however, definite chemical and physico-chemical changes take place, soluble materials are released, and new minerals are produced or are left as resistant end products.

Black cotton soil, are found mainly in the north eastern region of Nigeria and Jos Plateau which originated from the basalt rocks of the upper Benue trough derived its origin from the quartz sediments from the Chad Basin consisting of shale, clays and sandy sediments, NBRRI, (1983).

### **2.1.1 Physical weathering of rocks**

Rocks exposed to different environmental conditions are subjected to expansion and contraction resulting in disintegration. The rock pieces retain the chemical and petrological composition of the original parent rock. They usually occur in the surficial environments.

Physical weathering processes cause insitu breakdown without chemical change. Five processes are involved in the weathering, Mitchell and Soga, (2005):

1. Unloading
2. Thermal Expansion and Contraction
3. Crystal Growth, Including Frost Action
4. Colloid Plucking
5. Organic Activity

Physical weathering processes are generally the forerunners of chemical weathering. Their main contributions are to loosen rock masses, reduce particle sizes, and increase the available surface area for chemical attack.

### **2.1.2 Chemical weathering of rocks**

Chemical weathering involves the decomposition of rocks resulting in the production of secondary minerals, thus the chemistry and petrological characteristics of the parent rock is greatly altered. The process of chemical weathering commenced when the ingress and percolation of slightly acidic rainwater contaminated with organic impurities get into the soil.

## **2.2 Description of Black Cotton Soil**

Black clays or tropical black earth or black cotton soils are known to be potentially expansive soils (Osinubi *et al.*, 2010) which are “black” or “greyish black” or in their eroded phase “greyish white” heavy loam or clay (usually 50%), which is predominantly clay mineral of the smectite group, rich in alkali earth elements and the horizons sometimes contain calcium carbonate or magnesium oxide concretions.

Many other terms have been applied locally, such as “regur” soils in India, “margalitic” soils in Indonesia, “black turf” in Africa and “tirs” in Morocco. The term “black cotton” is believed to have originated from India where the locations of these soils favour cotton growth Gidigasu and Gawu (2013).

Black cotton soils have been defined differently by different authors, for instance, Mohr and Van Baren, (1959) proposed the term “margalitic soils” which they defined as “black or greyish black, grey or in the eroded phase greyish-white” heavy loam or clays; which crack when dry and swell when moistened, they are mostly rich in alkaline earths; horizons of calcium concretions develop sometimes or lime concretions are found scattered throughout the profile;

they are characterized by montmorillonite or other minerals of the smectite group as clay compound.

USAID/BRRI, (1971) also defined the tropical black cotton clay to be dark grey to black soil with a high content of clay usually over 50%, in which montmorillonite is the principal clay mineral and are commonly expansive.

Morin, (1971) defined black cotton soil as dark grey to black soil which has high clay content usually over 50% and are potentially expansive as shown in Table 2.1.

Bucher and Sailie, (1984) described black cotton soil as rich in montmorillonite and therefore prone to high volume change in the presence of water.

### 2.2.1 The characteristics of black cotton soils

1. Black or darkish grey to brown colour
2. High content of expansive clay mineral montmorillonite
3. Possess the tendency to shrink and swell with change in moisture condition
4. Exhibits heave and crack as geo-environmental phenomena.

**TABLE 2.1: GENERAL CATEGORIZATION OF BLACK COTTON SOIL OF NORTH-EASTERN NIGERIA**

S/No	Plasticity Index (%)	Free Swell (%)	% Lesser than 1 $\mu$ m	Swelling Potential
1	< 20	< 50	< 20	Low
2	15 - 30	50 - 80	15 - 30	Medium
3	> 30	> 80	> 30	High

Source: NBRRI, 1983

### 2.2.2 Mineralogical Properties of Black Cotton Soil

From mineralogical analysis it was found that black cotton soils consist of kaolinite and montmorillonite (Gidigasu and Gawu 2013). High percentage of montmorillonite renders high degree of expansiveness. These properties cause cracks in the soil without any warning. These

cracks may sometimes extend to severe limit like ½” wide and 12” deep. So building founded on this soil may suffer severe damage with the change of atmospheric conditions.

### **2.2.3 Chemical and clay mineralogical status of black cotton soils**

Chemical weathering is the main soil forming process of the black cotton soils. In this process, the minerals in the rocks are decomposed, resulting in chemical alteration. The chemical composition of the soils which will vary with such factors as parent rock, genetic characteristics of soil (transported or residual), degree of weathering, etc.

Typical oxide composition of some typical black cotton soils from some countries are presented in Table 2.2. The black cotton soils are rich in silica, lime, iron, magnesia and alumina. Titanium oxide also occurs in very small concentrations; however, its presence is believed to give the soil the characteristic black colour, Building and Road Research Institute, (1985).

In spite of its black colour, low organic matter contents (less than 5%) have been recorded for these soils USAID/BRRI, (1971) found that silica-sesquioxides ratios of the black cotton soils are greater than 2.50 indicating that they are non-lateritic soils.

**Table 2.2: Oxides composition of black cotton soils from some countries**

Major Oxides	Concentration by weight percent (%)					
	*India	**Nigeria	***Togo	****Ghana	*****Indonesia	
SiO <sub>2</sub>	49.30	31.01	46.37	54.26	62.18	42.80
TiO <sub>2</sub>	1.90	1.34	0.85	1.42	1.09	0.02
Al <sub>2</sub> O <sub>3</sub>	13.70	16.19	22.04	20.29	18.23	19.03
Fe <sub>2</sub> O <sub>3</sub>	14.80	4.74	12.83	10.22	6.70	8.68
MnO	-	0.13	-	0.29	0.07	0.05
MgO	4.80	-	2.20	2.78	2.45	1.81
CaO	6.90	-	0.37	0.16	0.70	1.73
Na <sub>2</sub> O	-	-	0.18	1.12	2.07	0.75
K <sub>2</sub> O	-	-	0.20	0.05	0.11	0.08
P <sub>2</sub> O <sub>5</sub>	-	-	-	0.05	0.004	0.06
SO <sub>3</sub>	1.6	-	-	0.04	0.1	-

Source: \*Katti *et. al.*, (2002); \*\*Osinubi and Ijimdiya, (2008); \*\*\*Oscar *et. al.*, (1977);  
\*\*\*\*Gidigasu and Gawu, (2013), \*\*\*\*\*Mohr and Van Baren, (1959).

### 2.3 Soil Stabilization

Soil stabilization is the improvement of the original soil properties to meet specific engineering requirements. It is aimed at the enhancement of the engineering properties of deficient soils to enable them perform and sustain their intended engineering use (Yoder and Witczak, 1975; Gillott, 1987; Osinubi, 1995; Nicholas and Lester, 1999; Oyelakin, 2011).

Its objectives are: improvement of the strength of the soil and bearing capacity, decreasing permeability and water absorption, and to increase the durability under varying moisture content.

### **2.3.1 Mechanical stabilization**

The stabilization of soils through mechanical means includes compaction, vibration (of various techniques) and blasting. Mechanical stabilization by compaction is the densification of the soil by the application of mechanical energy which involves reducing or total elimination of water as well as re - arrangement of the soil particles.

Cohesionless soils are compacted by some means of confining the soil coupled with vibration energy. In the field, hand–operated vibrating plates and motorized vibratory rollers of various sizes are very efficient in compacting sand and gravelly soils. Large falling weights have been used to dynamically compact loose granular fills Marwick, (1944)

Fine grained cohesive soils are compacted in the field by using common compaction equipment like hand – operated tampers, sheep foot rollers, rubber – tyred rollers and other types of special equipment. Considerable compaction can also be obtained by proper routing of the hauling equipment over the loose soil.

The objective of mechanical compaction is the improvement of the engineering properties of the soil mass, and the advantages which are obtained through compaction according to O' Flaherty, (1988) are as follows:

- i. Reduction in settlement due to reduced void ratio
- ii. Increase in soil strength
- iii. Reduction in shrinkage.

### **2.3.2 Chemical stabilization**

Generally, the addition of chemical compounds, to expansive soils increase the strength, bearing capacity and durability of the soil. These organic or inorganic chemical compounds perform as cementitious and bonding agents or water proofers/repellants, (Slate and Johnson, 1953; Gidigasu and Gawu, 2013).

Organic compounds including resinous and bituminous materials act as water proofers and sometimes behave similar to glue. These water proofing agents reduce the capacity for water intake and help the soil to retain its dry strength, even under wet conditions Bowles, (1979). Inorganic agents employed for soil stabilization include Portland cement, lime, slag, sodium silicate, etc. Their functions are to reduce plasticity and facilitate densification Balogun, (1991)

### **2.3.3 Stabilization of Expansive Soil Using Industrial Solid Wastes**

Industrial solid wastes are the wastes generated from various industrial processes. Researches have been conducted on stabilization of expansive soil using some industrial solid wastes described below.

#### **2.3.3.1 Fly Ash**

Fly ash is the ash produced by combustion of pulverized coal in coal-fired electric and steam generating plants.

**Pandian, et al., (2001)** added fly ash (class- F) up to 100% to black cotton soil at an increment of 10% and found that California Bearing Ratio (CBR) values of black cotton soil increased up to a 20% addition of fly ash beyond it, CBR decreased. It again increased and attained an optimum value when the percentage of fly ash was 70%.

**Sabat and Pradhan (2014)** investigated the effect of polypropylene fiber (content and length) on compaction properties, unconfined compressive strength (UCS), soaked CBR, and PS

of an expansive soil stabilized with optimum percentage (20%) of fly ash and had found the optimum percentage and optimum length of fiber as 1% and 12 mm respectively with improvement in strength and swelling behaviour.

#### ***2.3.3.2 Blast Furnace Slag and Cement***

**Cokca *et al.*, (2009)** had utilized ground granulated blast furnace slag and ground granulated blast furnace slag -cement to stabilize an artificially prepared expansive soil. Ground granulated blast furnace slag and ground granulated blast furnace slag -cement was added in proportions of 5% to 25% at an increment of 5%.

Also reported, that the stabilizers decreased the total amount of swell whereas the rate of swell was found to increase. After the leachates analysis it was concluded that if the expansive soil exists near the drinking water wells it should not be stabilized using these stabilizers.

**Osinubi, *et al.*, (2012)** studied the effect of compaction delay on strength characteristics of black cotton soil stabilized with blast furnace slag and cement, and found that compaction delay reduces the strength of the stabilized soil.

#### ***2.3.3.3 Admixtures***

**Pankaj, *et al.*, (2012)** in their study found that the thickness of pavement decreases by 66% as the CBR value goes on increasing. The improved CBR value was due to addition of Lime and Fly ash as admixtures to the black cotton soil. It also reduces the hydraulic conductivity of black cotton soil.

There will be no need of drainage layer after treatment of black cotton soil as sub grade with lime and fly ash. The combination of the admixtures is beneficial for lowering plasticity and higher silt content soils.

#### ***2.3.3.4 Cement Kiln Dust***

**Moses and Saminu (2012)** conducted a laboratory test on Black Cotton Soil with Cement Kiln Dust. They found that the natural black cotton soil was classified as A – 7 – 6 and CL in the AASHTO and Unified Soil Classification System (USCS), respectively. Soils under these groups are of poor engineering benefit.

They also observed that, cement kiln dust treated black cotton soil failed to record desired result. It was therefore, concluded that Cement Kiln Dust should not be used as a single stabilizing agent for road pavements.

#### ***2.3.3.5 Stabilization of Expansive Soil using Agricultural Solid Wastes***

Agricultural solid wastes are the wastes generated from the processing of various agricultural products.

#### ***2.3.3.6 Groundnut Shell Ash***

In a research conducted by (Oriola, *et. al*, 2010), where ground nut shell ash was used to stabilize black cotton soil. The following were their findings: That black cotton soil belongs to A – 7 – 6 or CL in the AASHTO and Unified Soil Classification System (USCS), respectively. Soils in these groups are not good for engineering purpose.

The durability of specimen determined in terms of resistance to loss in strength failed to meet the 80 % resistance to loss in strength recommended for 7 days cured and 4 days soaked samples and that, the stabilization of black cotton soil with groundnut shell ash was unattainable.

Their conclusion was that groundnut shell ash shows progressive strength development with longer curing periods from the observations of the 7, 14 and 28 days cured unconfined compressive strength of specimens.

### ***2.3.3.7 Portland cement - Locust Bean Waste Ash Blend***

**Osinubi et al; (2011)** carried out a preliminary investigation on the Nigerian expansive clay, also known as black cotton soil, collected from New Marte, Borno State, it was observed that the soil belongs to A-7-6 (13) in the AASHTO Soil Classification.

In the study, Ordinary Portland Cement - Locust Bean Waste Ash Blend was used to stabilize the soil collected from New Marte.

From the results, it was recommended that about 50% replacement of cement by the ash could be used for the treatment of the soil to achieve a sub base material, thereby reducing the quantity and cost of cement needed for stabilization and the environmental menace cause by the waste.

### ***2.3.3.8 Stabilization of Expansive Soil using Mineral Solid Wastes***

Mineral solid wastes are the wastes generated from various mining activities or the extraction of ores and minerals.

### ***2.3.3.9 Marble Powder***

**Sachin et al., (2014)** studied the behavior of Stabilized Black Cotton Soil with Marble Powder:

Performed the following test: Atterberg's limit tests, particle size distribution by wet sieve analysis, free swell index determination test, and linear shrinkage test on the sample of 50% black cotton soil + 50% marble powder.

He found that treatment of the soil with 50% marble powder has great improvement on engineering properties of black cotton soil. It also gives large decrement in swelling and shrinkage behavior of soil.

## 2.4 Palm Kernel Shell Ash (PKSA)

Palm Kernel Shell Ash (PKSA) with oxides composition shown in Table 2.3, was obtained by burning palm kernel shell which is the by-product of Oil Palm - "*Elaeis*" (which means oil in Greek) is available in two species, one of which, *Elaeis Guinensis*, is available in the western and south-western Africa and in Southeast Asia, while the other, *Elaeis Oleifera*, is available in central and South America.

Oil palm produces an edible fruit that resembles an apricot with a nut inside. Oil palms are used primarily for the production of palm oil *Elaeis Guinensis* is available in three different variants:

1) Dura which has fruits with large kernel with thick shell; 2) Pesiferá which has small fruits without kernel; and 3) Tenerá which is hybrid of Durá and Pesiferá with thick fleshy outer layer and small kernel.

It is obvious that only Durá and Tenerá reveal palm kernel shells. Durá are mostly found in Africa, while Tenerá mostly found on farms in Asia. This has to do with the fact that production in Africa is dominated by small and medium size family owned farms which have been around for generations, while Asian - especially Malaysia and Indonesian - is completely dominated by large industrial farms.

Mature palm trees are single-stemmed and grow up to 20 meters high. The leaves are pinnate and up to 3-5 meters long. The flowers are in dense clusters, each flower is small with three sepals and three petals.

Palm fruits take 5-6 months to mature from pollination to the ripe fruits. The palm fruit is reddish and about the size of a large plum and grows in large bunches. Each fruit is composed of

an oily fleshy outer layer with one seed (core), which is also rich in oil. Once the fruit is ripe considering each class weights 23-27 kg for Durá and 40-50 kg for Tenerá. The high oil yield of oil palm (as high as 7,250 liters per hectare annually for Tenerá) has made it a common ingredient in cooking in Southeast Asia and in the tropical belt of Africa. Its increasing use in the commercial food industry in other parts of the world is buoyed by its cheap pricing and the high oxidative stability of the refined product with high levels of natural antioxidants.

Palm Kernel Shells is regarded as a natural high quality solid renewable fuel, either alone or with coal possibly mixed with other types of biomass such as wood chips.

**Table 2.3: Typical Oxides Composition of Palm Kernel Shell Ash**

<b>Oxides formula</b>	<b>Oxide Components</b>	<b>Percentages</b>
K <sub>2</sub> O	Potassium Oxide	6.62%
CaO	Calcium Oxide	10.8%
Fe <sub>2</sub> O <sub>3</sub>	Iron Oxide	3.98%
MnO	Manganese Oxide	0.39%
ZnO	Zinc Oxide	0.48%
CuO	Copper Oxide	0.091%
BaO	Barium Oxide	0.44%
P <sub>2</sub> O <sub>5</sub>	Lead Oxide	3.5%
SO <sub>3</sub>	Sulphite	0.9%
SiO <sub>2</sub>	Silicate	15.1%
Al <sub>2</sub> O <sub>3</sub>	Aluminium Oxide	0.032 – 0.05

**Source:** Journal of Sustainable Development and Environmental Protection and Otunyo et al, (2011).

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Materials

##### 3.1.1 Black cotton soil

The soil sample used in this study is black cotton soil (dark brown in colour), which is called “Kasan Kalar” by the community was obtained from Baure in Yamaltu/ Daba Local Government Area of Gombe State, using the method of disturbed sampling for the collection. The location lies within latitude  $10^{\circ} 13'N$  and longitude  $11^{\circ} 23'E$ .

The soil was collected from depths in the range 1.0 – 2.0 m to obtain true representative sample of the soil, air-dried and all the clods and lumps in the sample were broken and well pulverized classification test was carried out on the sample collected.

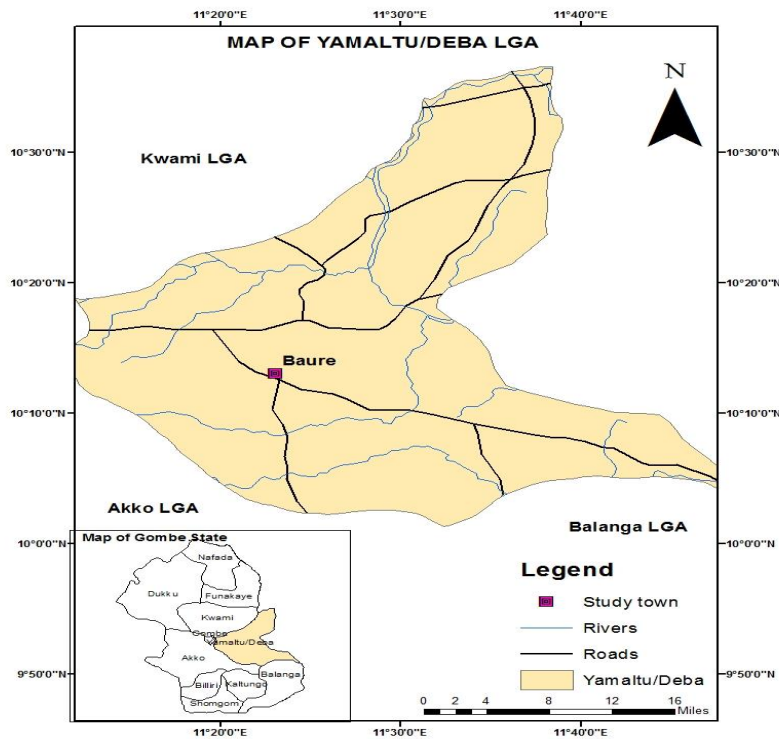


Plate 2: Map of the Baure in Yamaltu/Deba Local Government Area, Gombe State

### **3.1.2 Palm kernel shell ash**

The ash was obtained from burning of palm kernel shells collected from a palm oil processing mill in Abeokuta, Ogun State. The palm kernel shells (see Plate 1) was collected from waste dump around palm oil processed mill and the dirt's or impurities was removed. The shell was sun dried for 4 days to facilitate proper combustion during burning.

The ash formed was allowed to cool and then sieved through No. 200 sieve (75  $\mu\text{m}$  aperture). The ash was stored in an airtight container to prevent gain or loss of moisture and any form of contamination.

### **3.1.3 Water:**

The only portable water available in the laboratory was used for the study.

## **3.2 Methods**

The following tests were carried out on the natural and treated black cotton soil in accordance with BS 1377 (1990) and BS 1924 (1990), respectively using three compactive efforts, British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH).

The listed tests were carried out varying palm kernel shell ash (PKSA) content in stepped concentration of 2 % (i.e., 0, 2, 4, 6, 8 10, and 12%) to improve the engineering properties of the soil.

Tests include:

1. Natural Moisture Content
2. Sieve analysis
3. Atterberg limits
4. Compaction
5. California bearing ratio

6. Unconfined compression
7. Durability
8. California Bearing Ratio
9. Cation Exchange Capacity
10. Scanning Electron Micro-Scope

### **3.2.1 Natural Moisture Content**

The natural moisture content of the black cotton soil (BCS) was determined in accordance with BS 1377 (1990) Part 2; A weighing container was cleaned and weighed to the nearest 0.1 g. Sample was taken and placed in the weighed container. The container with sample were weighed to the nearest 0.1 g and placed in a thermostatically controlled oven and dried at temperature 105-110 °C for 24 hours. The dried sample and container were then weighed to the same accuracy.

Moisture content was determined using equation (3.1):

$$w = \frac{m_3 - m_2}{m_2 - m_1} \times 100 \quad (3.1)$$

where:

w = Moisture Content

m1 = Mass of Container

m2 = Mass of Container plus Dry Sample

m3 = Mass of Container plus Wet Sample

### **3.2.2 Particle Size Distribution Analysis**

#### **3.2.2.1 Wet sieving**

Particle size analysis was carried out in accordance with BS 1377; 1990 Part 2. Wet sieving was conducted by measuring 200 g of the soil sample and soaking it for 24 hours. The sample was then washed through BS No 200 sieve. The particles retained were then dried in an

oven for 24 hours and dry sieving was carried out on the dried sample to obtain the particle size distribution.

The mixture that passes through sieve No 200 was poured into a 1000 ml measuring cylinder then 250 ml of sodium hexametaphosphate (commercial grade) was added and stirred thoroughly, then hydrometer was immersed gently and readings were taken at intervals stipulated by BS 1377; 1990 part 2.

For corrected hydrometer reading and effective distance the followings  $F$ ,  $L$ ,  $CT$ , and  $a$  were obtained from Table A3.1 – A3.4 in Appendix respectively. The diameter of the grain and the percentage passing were calculated by equations (3.2) and (3.3) respectively.

$$D = F\sqrt{\frac{L}{t}} \quad (3.2)$$

$$P = R \frac{G_s}{G_s - G_w} \times \frac{100}{w} \quad (3.3)$$

where,

$C_T, a$  – Correction factor for temperature and unit weight from TableA3.3 and A3.4 respectively in appendix

$F$  – Correction factor from TableA3.2 in appendix

$L$  – Effective distance from TableA3.1in appendix

$D$  – Diameter of sample grain and

$t$  – Time in minutes

$P$  – Percentage passing

### 3.2.2.2 Dry sieving

The particle size analysis test was carried out in accordance with BS 1377; 1990 Part 2, dry sieving was conducted by weighing 200 g of the dry soil sample that passed No. 4 sieve

(4.76 mm aperture).The dry sample was then mixed properly with the optimum moisture content of the mix obtained from compaction test and air-dried under shade for 48 hours. Dry sieving was carried out on the dried sample to obtain the particle size distribution.

### ***3.2.3 Atterberg Limits***

The Atterberg Limits tests included the determination of liquid and plastic limits, and plasticity index of the natural and treated soil samples. They were also conducted in accordance with B S 1377 (1990) Part 2 for the natural soil and BS 1924 (1990) for the stabilized soils

#### ***3.2.3.1 Liquid limit***

The soil sample for liquid limit was air dried, pulverized and 200g of the material passing through BS No 40 sieve (425 $\mu$ m aperture) was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil water mixture is then placed in the cup of the Casagrande apparatus, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the centre of the hinge.

The cup was then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove.

The number of blows at which that occurred was recorded and a little quantity of the soil was taken and its moisture content determined. The test was performed for well-spaced out moisture content from the drier to the wetter states.

The values of the moisture content (determined) and the corresponding number of blows was then plotted and the liquid limit was determined as the moisture content corresponding to 25 blows.

This same procedure was then repeated for each of the samples with the mixture of the sample and palm kernel shell ash for the various percentages considered in this study.

### **3.2.3.2 Plastic Limit**

A portion of the soil/soil – palm kernel shell ash mixtures used for the liquid limit test was retained for the determination of plastic limit (PL). The ball of the soil / treated soil was moulded between the fingers and rolled between the palms of the hand until it dried sufficiently. After the liquid limit test has been determined, small portion of the soil paste were taken and then tried to roll into a 3mm thread.

The moisture content at which the soil can be rolled into a thread of 3 mm without crumbling is the plastic limit of the soil. A portion of the rolled soil thread was then put in to the oven for moisture content determination.

This experiment procedure was repeated three times in other to get the average moisture content which corresponds to the plastic limit. The same procedure was repeated for all the percentages of the treated soil.

### **3.2.3.3 Plasticity Index**

The plasticity index (PI) of the soil/treated soil is the difference between the liquid limits of the natural/various mixes of the soil and their corresponding plastic limits. Mathematically it is expressed as shown in equation (3.4)

$$PI = LL - PL \quad (3.4)$$

where;

PI=Plasticity Index (%)

LL=Liquid Limit (%)

PL= Plastic Limit (%)

### **3.2.3.4 Linear shrinkage**

The test was conducted in accordance with Test 5 BS 1377 (1990). It involves the mixing of about 125 g of soil passing the 425 µm sieve (BS No. 40 sieve) with water in order to obtain a

homogenous paste (the water added to the natural soil corresponded to the moisture content at liquid limit). With the same sample used for the liquid limit, a portion of the paste was also used to fill the shrinkage mould whose inner surface was oiled to prevent sticking of the sample to the mould. The top of the mould was leveled and smoothen. The same sample was then put into the oven for 24 hours at 105<sup>0</sup>C. The length of the shrinkage mould and the length of the dry soil in the mould were measured. This same procedure was then repeated for each of the sample with palm kernel shell ash. Linear shrinkage was calculated using the expression shown in equation (3.5):

$$\text{Linear Shrinkage, } LS \text{ (\%)} = \frac{\text{Change in length } (\Delta l)}{\text{Original length } (l_0)} \times 100 \quad (3.5)$$

where;

$$\Delta l = \text{Original length (length before drying)} - \text{length after drying}$$

### 3.2.4 Free Swell

The test was conducted in accordance with the United States Bureau of Reclamation (USBR) method (Holtz and Gibbs, 1956). About 10 g of soil passing BS No 4 sieve (425 μm aperture) was oven dried and allowed to cool down in a desiccator. The sample was slowly poured into a 100 cm<sup>3</sup> measuring cylinder to which water was added in order to fill the cylinder.

The cylinder was then agitated in order to obtain a homogenous mixture of soil and water after which it was allowed to settle for 2 hours or more before the swell volume was recorded.

Free swell was calculated using equation (3.6):

$$\text{Free Swell} = \frac{\text{Final Volume} - \text{Initial Volume}}{\text{Initial Volume}} \times 100 \quad (3.6)$$

### **3.2.5 Compaction Characteristics**

#### ***3.2.5.1 Maximum dry density***

The compaction tests were carried out for the natural soil and the modified soils (in different percentages); all according to BS 1377 (1990) and BS1924 (1990), using the British Standard light (BSL), West African Standard (WAS) and the British Standard heavy (BSH) compactive energies.

The WAS energy was applied in accordance with the Nigerian General Specification (1997). 3kg of the soil was hydrated with 70% of the initial water required for the mix and after 24hours, the remaining 30% of water and the ash was added in step of 2% and the mixture were thoroughly mixed (and water was added in step of 6% for each of the compactions).

The sample was then compacted into the 1000 cm<sup>3</sup> (of mass m<sub>1</sub>); in three layers of approximately equal mass with each layer receiving 27 blows of 2.5kg rammer falling through a height of 300mm, for the BSL compaction; 10 blows of 4.5kg rammer in five layers for West African Standard compaction and 27 blows of 4.5kg rammer in five layers for the British Standard heavy.

The blows were uniformly distributed over the surface of each layer. The collar was then removed and the compacted sample leveled off at the top of the mould with a straight edge. The mould containing the leveled sample was then weighed to the nearest 1g; m<sub>2</sub>. Two small samples were then taken from the top and bottom of the compacted soil for the determination of moisture content.

The sample was then removed from the mould, crushed, and water added and the same procedure was repeated until drop in the density of the sample was observed, samples were then taken from the top and bottom for moisture content determination.

The bulk density ( $\rho$ ) in Mg/m<sup>3</sup> was later calculated for each compacted specimen using equation (3.7):

$$\rho = \frac{\text{mass}}{\text{volume}} = \frac{m_2 - m_1}{1000} \quad (3.7)$$

The dry density ( $\rho_d$ ) was also calculated using the equation (3.8)

$$\rho_d = \frac{100\rho}{(100 + w)} \quad (3.8)$$

where,

w - is the moisture content of the compacted soil and soil mixture.

The values of the dry densities obtained from eq. (3.7) were plotted against their respective moisture contents and the maximum dry density, MDD was obtained as the maximum point on the resulting curves.

### **3.2.5.2 Optimum moisture content**

The corresponding values of moisture contents at maximum dry densities (MDD), obtained from the graph of dry density against moisture contents, gives the optimum moisture contents (OMC).

## **3.2.6 Strength Parameters**

### **3.2.6.1 Unconfined compressive strength**

The shear strength tests were carried out using the undrained triaxial test procedure in accordance with BS 1377 (1990) at the maximum dry densities and optimum moisture contents of the soil treated with various percentages of the ash.

The natural soil sample/the treated soil samples were compacted in 1000cm<sup>3</sup> moulds at their respective OMCs. The samples were extruded from the moulds and trimmed into a cylindrical specimen of 38.1mm diameter and 76.2mm length.

The three cylindrical specimens from the mould were then weighed before carrying out the test. Record was taken simultaneously of the axial deformation and the axial force at regular intervals until failure of the sample occurred. The compressive strength was calculated from the following Head, (1992) and equations (3.9) to (3.11)

$$\sigma = \frac{R \times Cr \times (1 - \varepsilon)}{A_o} \times 1000 \text{ (KN/m}^2\text{)} \quad (3.9)$$

$$E = \frac{\sigma}{\varepsilon} \left( \frac{MN}{m^2} \right) \quad (3.10)$$

Where;

$$A_o = \text{Initial cross sectional area} = \frac{\pi D^2}{4} \quad (3.11)$$

$\varepsilon$  (%) = Strain percent =  $\Delta l/l_o$

$\Delta l$  = compression at any stage

$l_o$  = Initial length of the specimen

R = Load ring reading at strain E

$C_r$  = Load ring Constant/factor

D = Diameter of the specimen (m)

E = Modulus of Elasticity

### ***3.2.6.2 Durability assessment (Resistance to Loss in strength)***

The durability assessment (under adverse field conditions) of the soil sample was determined by resistance to loss in strength when immersed in water. It was expressed as the ratio of UCS of the specimen cured for 7 days and soaked for another 7 days to the UCS of the specimen cured for 14 days. Ola (1974) proposed 80% resistance to loss in strength for the ratio

of the UCS of a specimen cured for 7 days and soaked for 4 days to the UCS of the specimen cured for 14 days. The calculation is express by equation (3.12).

*Resistance to loss in strength (%)*

$$= \frac{UCS(7days\ cured + 7days\ immersed\ in\ water)}{UCS(14days\ cured)} \times 100 \quad (3.12)$$

Test results for 7 days soaking then 7 days curing UCS values are summarized in Tables A3.1 (a - b) while the test results for the resistance to loss in strength are shown in Table A3.1(c).

### **3.2.7 California Bearing Ratio**

The California bearing ratio (CBR) test was conducted in accordance with BS 1377 (1990) and BS 1924 (1990) for the natural and treated soils. The CBR is expressed by the force exerted by the plunger and the depth of its penetration into the specimen; it is aimed at determining the relationship between force and penetration.

5.0 kg of the soil sample were mixed with 70% of the optimum moisture content to hydrate the soil sample for 24hours, after which soil and the ash sample were mixed with the remaining 30% of the optimum moisture contents in 2360 cm<sup>3</sup> mould, at the three compactive energies.

For BSL, the compaction was in three layers each receiving 62 blows from the 2.5 kg rammer; for the WAS, the samples were compacted in five layers with 25 blows from the 4.5 kg rammer and the BSH, the sample received 62 blows in 5 layers from the 4.5 kg rammer.

The base plates were removed (after compaction) and the compacted specimens placed in sealed plastic bags for curing (for 6 days) and after the sixth day, the specimens were immersed in water for 24 hours before testing according to Nigerian General Specifications (1997). The

base plates were later replaced and the specimens transferred to the CBR testing machine and positioned on the lower plate of the machine. The plunger was then made to penetrate the specimen at a rate 1.5 mm/min until the specimen failed. The mould was then inverted, base plate removed and the procedure repeated for the bottom of the specimens.

From the values of the penetration and force recorded, a curve of force against penetration was obtained. The CBR value was calculated at penetration 2.54 mm or 5.08 mm; the greater of the two values and as their means where the value are within 10 % of each other. The CBR was calculated as by equation (3.13):

$$CBR = \frac{\text{Measured Load}}{\text{Standard Load}} \times 100 \quad (3.13)$$

Where: standard load = 13.24kN at 2.5mm penetration  
= 19.96kN at 5.0mm penetration

### **3.2.8 Cation Exchange Capacity**

The cation exchange capacity (CEC) test was carried out in accordance with the procedures given by ISRIC (1998) 10 g of 2 mm sieved soil was put into a 100 m<sup>3</sup> plastic beaker, about 40 ml of Ammonium acetate (0.1N pH7.0) was added, stirred with a glass rod and left over night. The soil was filtered with a light suction using a 55 mm Bucher funnel, the soil was leached so that it could fit in a funnel with Ammonium acetate of a volume of 250 cm<sup>3</sup>.

The leachate was tested from the soil to know if it was calcium free, the presence of calcium was indicated by a white precipitate or turbidity. The electrolyte was washed out with 150 - 200 ml of isopropyl alcohol. Chloride was tested for in the leachate with (0.1N AgNO<sup>3</sup>) till

the leachate became negligible, the soil was tested to drain thoroughly, then the leached soil was acidified to a volume of 250 ml. 50 ml of boric acid was measured into 250 ml conical flask and a few drops of mixed indicator was added.

The acidified soil was poured into a 500 ml flask and the flask was connected to the steel, some anti-bump and 10 ml of 1N NaOH was added into the flask and distilled over the boric acid in the conical flask, 150 ml distilled was collected. The NH<sub>4</sub>-borate was titrated with a standard acid 0.1N HCl. The cation exchange capacity (CEC) was calculated using the formula shown by equation (3.14):

$$CEC = \frac{(Titre\ value - B) \times NA}{Weight\ of\ the\ soil} \times 100 \quad (3.14)$$

Where,

*B = Blank and NA = Normality of Acid*

This same procedure was then repeated for each of the treated sample.

### **3.2.9 Specific Gravity**

The determination of specific gravity was carried out according to BS 1377 (1990) for fine-grained soils. The density bottle and the stopper were weighed to the nearest 0.001g (m<sub>1</sub>). The air dried soil was transferred into the density bottle, and the bottle, content and the cover were weighed as m<sub>2</sub>. Water was then added just enough to cover the soil, the solution was gently stirred to remove any air bubble.

The bottle was then completely filled up and covered. The covered bottle was then wiped dry and the whole weighed to the nearest 0.001g (as m<sub>3</sub>). The bottle was subsequently emptied and filled completely with water, wiped dry and weighed to the nearest 0.001g (m<sub>4</sub>). The specific gravity is calculated using eqn. (3.15):

$$G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \quad (3.15)$$

The procedure was repeated for the various mixtures.

### 3.2.10 Microanalysis

The procedures adopted for micro analysis was in accordance with that described by Kozłowski *et al.* (2011). The scanning electron microscope (SEM) observations were carried out on air-dried samples of 8 - 10 mm in diameter. Such sample preparation in the case of soils in which contacts between structural units are stable lead to practically no microstructural changes during drying.

The samples were broken and covered by a layer of gold of approximately 40 nm to prevent ionization. The observation of the surface of the fracture was made by scanning electron microscope by applying voltage of 15 kV.

As a rule, only surfaces parallel to stratification were examined. The photographs were taken at two magnifications: x4800 and x5300. The lesser magnification images was used to determine the quantitative pore space parameters, while the x5300 magnification images made it possible to characterize the microstructure qualitatively, among other things to determine the types of contacts.

The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens.

The signals derived from electron – sample interaction revealed the following information about the sample, the external morphology (texture), the chemical composition (EDS), the crystalline structure and the orientation of materials making up the sample, Yohanna, (2015).

### **3.2.11 Analysis**

The two methods of analysis used in this research are:

1. Graphical method using Microsoft excel software package.
2. Statistical Analysis: One-way analysis of variance (ANOVA) using the Microsoft excel software package.
3. Regression Analysis using Microsoft Excel Statistics (XLSTAT)

#### ***3.3.11.1 Graphical method using Microsoft Excel software package.***

In the Graphical method using Microsoft Excel software package, graphs were used to show the relationship between two quantities. An independent variable usually plotted on the X-axis and a dependent variable on the Y-axis. The graphs were plotted using the Microsoft excel package.

#### ***3.3.11.2 Statistical Analysis using Microsoft Excel software package.***

In this method, the statistical package in Microsoft Excel software was used to analyze the results of the test carried out on the soil - pksa mixtures based on the one - way analysis of variance (ANOVA). The aim of the analysis was to find out if there was any significant effect on the various black cotton soils – pksa mixtures.

#### ***3.3.11.3 Regression Analysis using Microsoft Excel software package (XLSTA)***

This package was used to generate model equation for strength characteristics of the soil - pksa mixture with the aim of determining the relationship between geotechnical and strength characteristics of the mixture.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Properties of the Material Used in the Study

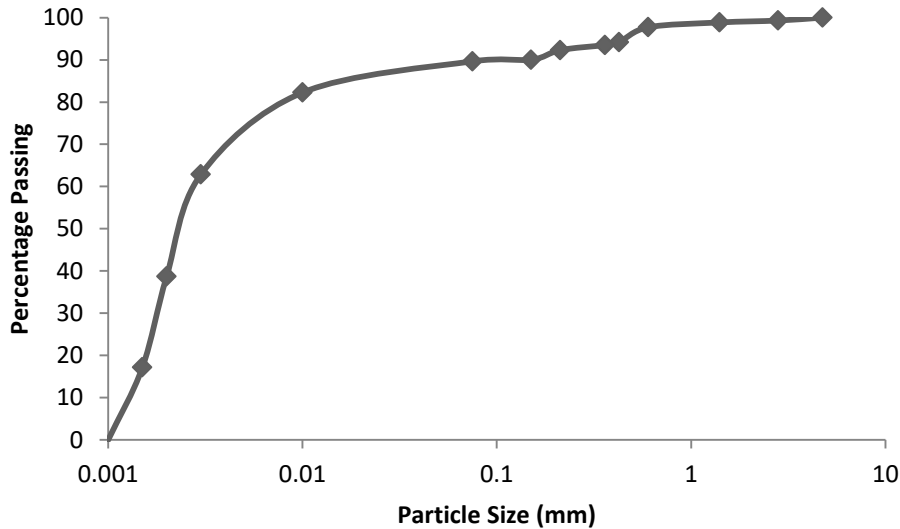
##### 4.1.1 The natural black cotton soil

The results of the tests conducted for the identification /determination of the properties of the natural soil before modification are presented in Table 4.1. The particle size distribution curve for the natural soil is shown in Figure.4.1. The percentage passing sieve No. 200 sieve (75 µm size) in wet sieving analysis was 89.7 %, hence the soil is classified as an A-7-5 (20) subgroup soil based on the American Association of State Highway and Transportation Officials Soil Classification System (AASHTO, 1986) and CH based on the Unified Soil Classification System, USCS ASTM, (1992). The soil is greyish black in colour and has a liquid limit of 76.2 %, plastic limit of 40.0 %, plasticity index of 36.2 %. The natural black cotton soil has a free swell value of about 81.7 %.

The Highway Research Board (1943) and Nigerian General Specifications (1997) specify that the limits of 50 % passing No. 200 sieve, 40 % liquid limit and 18 % plasticity index is required for base and sub base materials. Based on the results summarized in Table 4.1a the natural soil is not suitable for use as a base or sub base material in road construction.

**Table 4.1a: Properties of the natural black cotton soil**

<b>Property</b>	<b>Value</b>
Natural Moisture Content (%)	26.8
Percentage Passing No. 200 Sieve	89.7
Liquid Limit (%)	76.2
Plastic Limit (%)	40.0
Plasticity Index (%)	36.2
Linear Shrinkage (%)	21.3
AASHTO Classification	A – 7 – 5 (20)
Unified Soil Classification System	CH
Specific Gravity	2.29
Free Swell (%)	81.7
Nigerian Building and Road Research Institute	High swell potential
Cation Exchange Capacity (cmol/kg)	53.5
Maximum Dry Density (Mg/m <sup>3</sup> )	
British Standard light	1.45
West African Standard	1.50
British Standard heavy	1.65
Optimum Moisture Content (%)	
British Standard light	28.5
West African Standard	22.4
British Standard heavy	18.2
Unconfined Compressive Strength (kN/m <sup>2</sup> )	
British Standard light	119.54
West African Standard	228.94
British Standard heavy	329.91
California Bearing Ratio (%) (Soaked)	
British Standard light	1
West African Standard	1
British Standard heavy	3
California Bearing Ratio (%) (Unsoaked)	
British Standard light	3
West African Standard	8
British Standard heavy	11
Colour	Greyish Black



**Figure 4.1: Particle size distribution curve of the natural black cotton soil**

#### **4.1.2 Chemical compositions of the materials used in the study**

The chemical compositions of black cotton soil (BCS) and palm kernel shell ash (PKSA) determined by X-Ray Diffraction (XRD) are presented in Table 4.1b. Both BCS and PKSA contain aluminium oxide ( $\text{Al}_2\text{O}_3$ ), calcium oxide or free lime ( $\text{CaO}$ ), ferric oxide ( $\text{Fe}_2\text{O}_3$ ), silicon dioxide or silica ( $\text{SiO}_2$ ) and other compounds in different proportions.

It was also observed that the ash has higher percentage in other compounds, hence will increase the percentages of the compounds in the soil when mixed together. The  $\text{CaO}$  is responsible for hydration reaction (a chemical addition reaction where a hydroxyl group and proton are added to a compound) between the materials.

ASTM C618 –78(1978) specify the combined weight of silica, alumina and ferrous oxides greater than 70% for classes of N, C and F pozzolana. The addition of the combined weight of silica, alumina and ferrous oxides is 75.2 % and based on other tests recommended by ASTM C618 which includes Sulphite ( $\text{SO}_3$ ), Moisture Content and loss on ignition, then, the PKSA used in the research is classified as F Pozzolans.

**Table 4.1b: Chemical compositions of black cotton soil and palm kernel shell ash**

Chemical Composition	Concentration (%)	
	*Black Cotton Soil	Palm Kernel Shell Ash
Na <sub>2</sub> O	-	4.39
MgO	-	7.59
Al <sub>2</sub> O <sub>3</sub>	16.70	16.91
SiO <sub>2</sub>	43.01	44.42
P <sub>2</sub> O <sub>5</sub>	-	4.06
K <sub>2</sub> O	-	13.40
CaO	-	2.97
TiO <sub>2</sub>	0.89	0.61
Fe <sub>2</sub> O <sub>3</sub>	5.30	5.65
SO <sub>3</sub>	-	3.25
PH	7.86	8.60

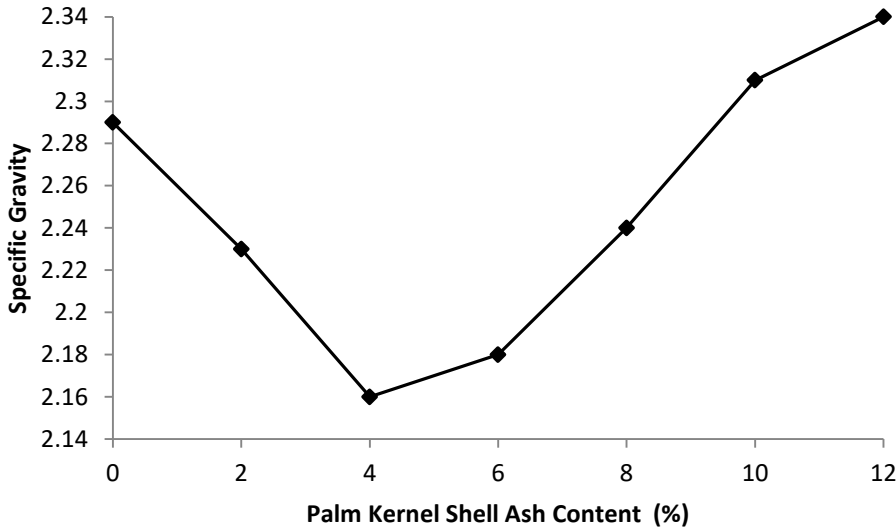
## **4.2 Effect of Palm Kernel Shell Ash on the Properties of Black Cotton Soil**

### **4.2.1 Specific gravity**

The variation of specific gravity of black cotton soil with palm kernel shell ash content is shown in Figure 4.2. It was observed that specific gravity of the mixtures considered increased with higher palm kernel shell ash content. The value of specific gravity of the soil decreased from 2.29 for the natural soil to a value of 2.16 at 4 % treatment soil and thereafter progressively increased to 2.34 at 12 % treatment.

The initial decrease may be due to partial replacement of the soil particles by the palm kernel shell ash which is less dense (with specific gravity of 1.57) when compared with that of the soil (with specific gravity of 2.29). On the other hand, the observed increase may be due to: (i) fine particles of the palm kernel shell ash that filled the void between the larger particles of black cotton soil, leading to higher density of the BCS - PKSA mixture (Edeh *et al.*, 2012) and (ii) rearrangement of BCS - PKSA mixture particles in phase-to-phase structures resulting from

cation exchange reactions of the mixture Azige, (2012). The detailed tests results are given in Table A4.2 (a -g): in the Appendix.



**Figure 4.2: Variation of specific gravity of black cotton soil with palm kernel shell ash content**

The one – way analysis of variance (ANOVA) test on specific gravity results shown in Table 4.2 indicate that the effect of palm kernel shell ash on black cotton soil is statistically significant ( $F_{Cal} > F_{Crit.}$ )

**Table 4.2: One - way analysis of variance result for specific gravity of black cotton soil – palm kernel shell ash mixtures**

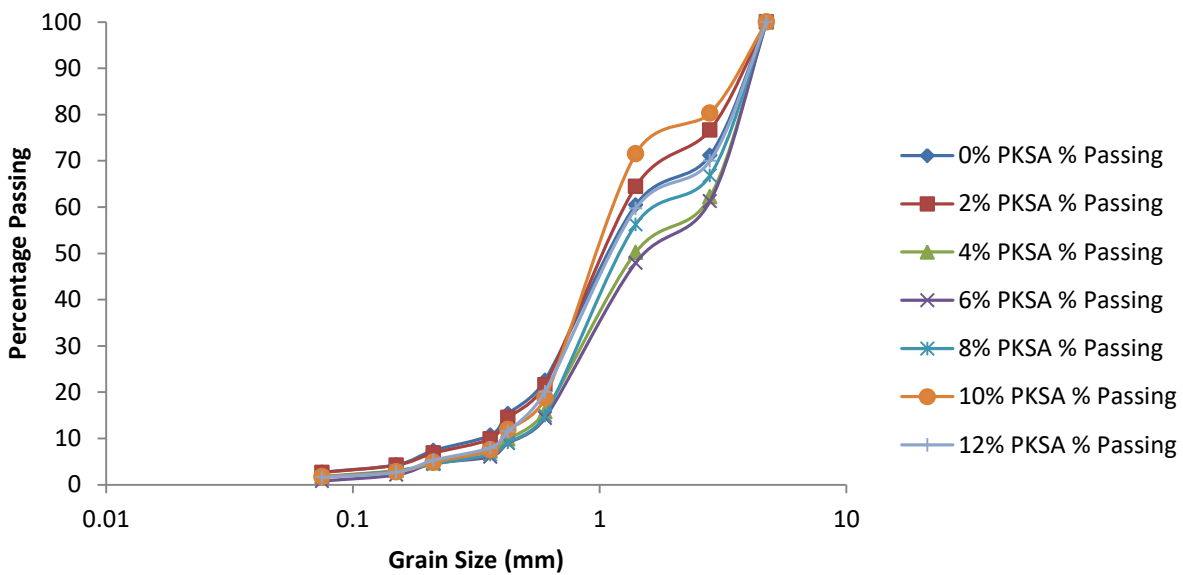
Property	Source of Variation	Degree of Freedom	F calculated	P-value	F critical	Remarks
Specific Gravity	Palm Kernel Shell Ash	1	6.385	0.0241	4.600	Significant Effect

#### 4.2.2 Dry sieving using optimum moisture content from British Standard light compaction

The particle size distribution curves of black cotton soil – palm kernel shell ash mixtures using optimum moisture content from BSL compaction are shown in Figure 4.3a. An increase in the percentage of fines was noticed when palm kernel shell ash was added.

A change was also observed in the grain sizes especially at 600  $\mu\text{m}$ . This was in agreement with the findings reported by Sani (2009).

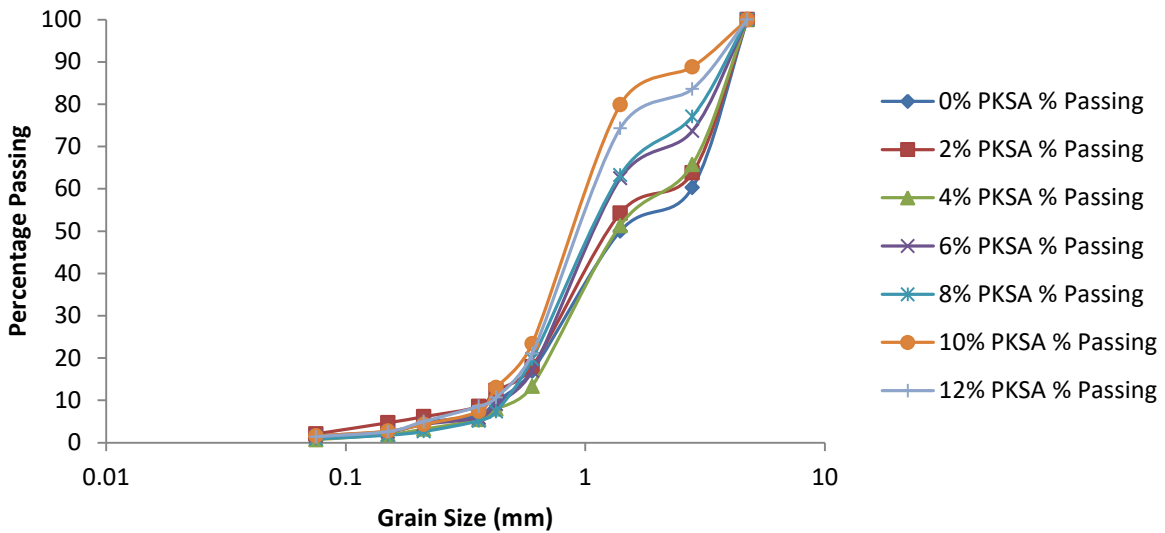
The increase in fine particles was due to the addition of palm kernel shell ash which is finer than the soil, acted as a nucleus to which the soil particles adhered. With increase in the ash contents the quantity of free silt and clay progressively reduced and coarser materials were formed, this is in agreement with the findings reported by Mu'azu (2007).



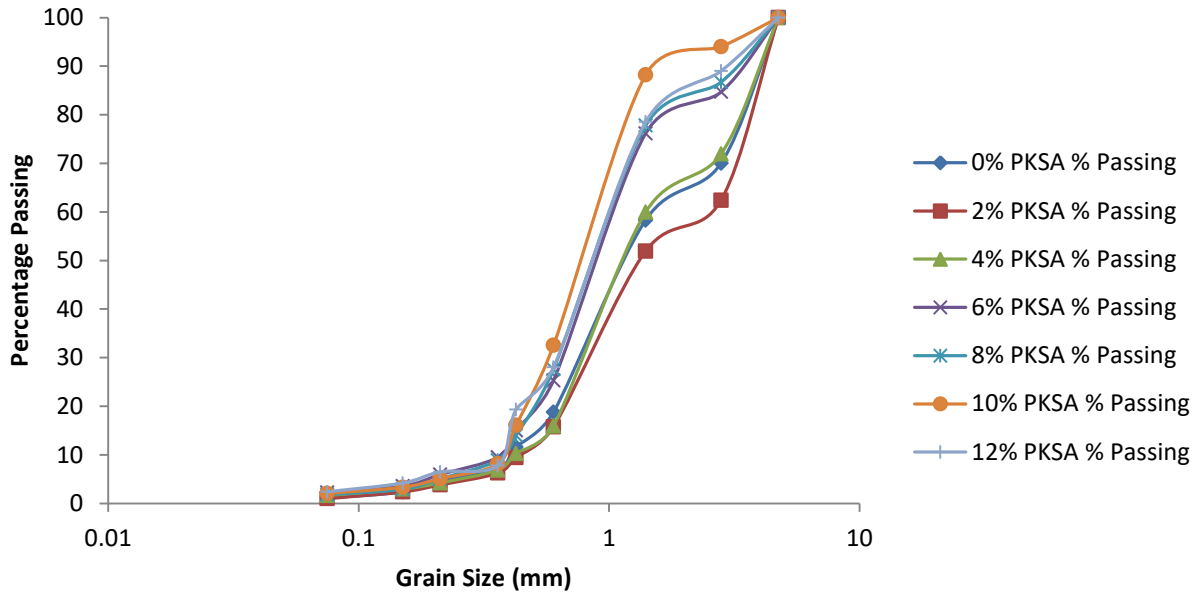
**Figure 4.3a: Particle size distribution curves of black cotton soil palm kernel shell ash mixtures (BSL compaction)**

Similar effect as in BSL was observed for WAS and BSH shown in Figure 4.3b and Figure 4.3c respectively, The PKSA content caused the soil to flocculate and agglomerate more and hence the soil – PKSA mixture became coarser enabling the clay particle to form pseudo silt sizes.

There was a reduction in the percentage of fines with increase in PKSA content as shown by the curves in Figure 4.3 and detailed result in Table A4.3 (a – c). A little change was noticed in the percentage of coarser particles which is due to exchange of cation between the clay particles and also in agreement with the findings reported by Sani (2009). The detailed tests results are given in Table A4.3a – c in the Appendix.



**Figure 4.3b: The grain size distribution of treated black cotton soil at optimum moisture content of West African Standard compaction**

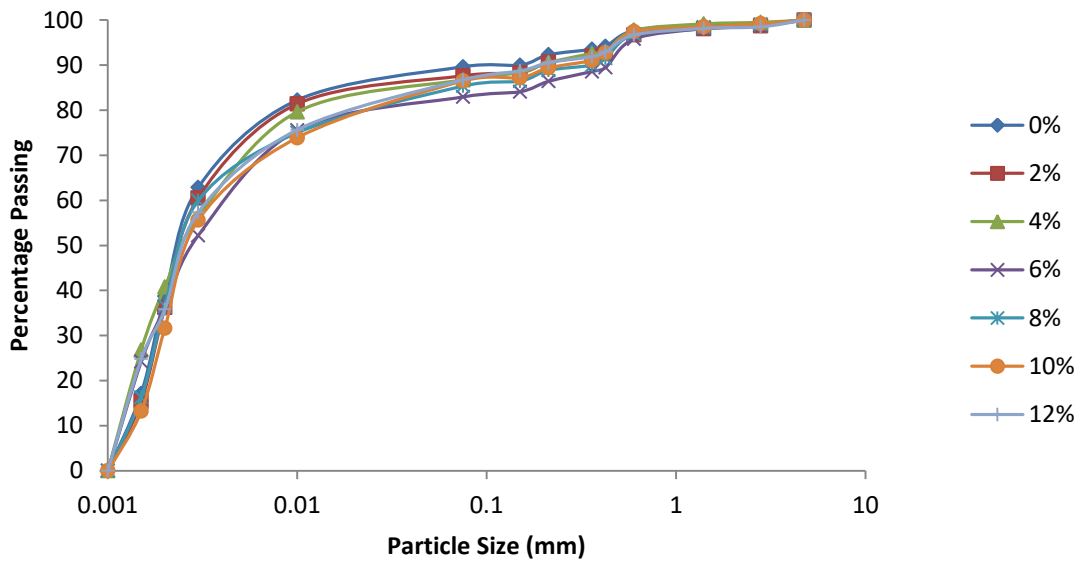


**Figure 4.3c: The grain size distribution of treated black cotton soil at optimum moisture content of British Standard Heavy compaction**

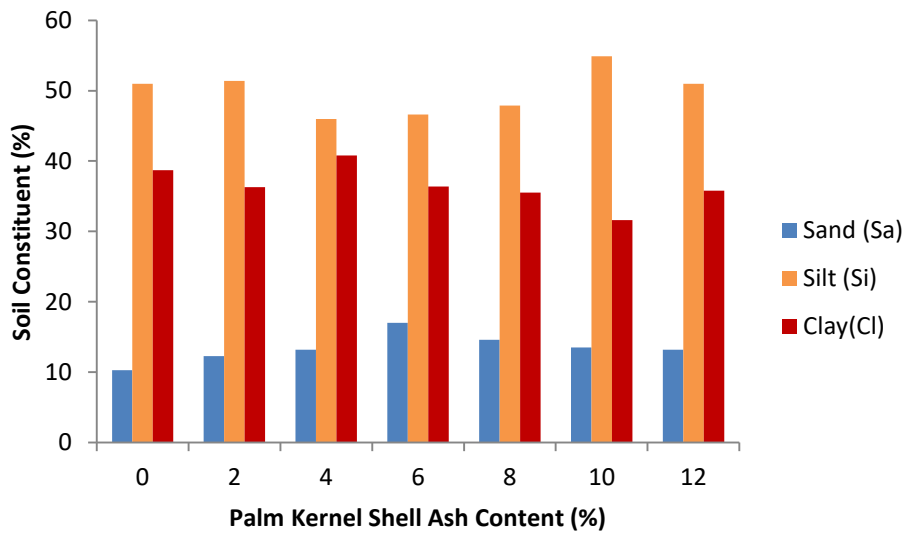
#### 4.2.3 Wet Sieving

The particle size distribution from hydrometer test for the natural and treated soil samples are shown in Figure 4.4 (a - b) and detailed result in Table A4.4 (a - b) of the Appendix. The following observations were made, in sand fraction there was an increase in the percentage of sand fraction from 10.3 % at 0 % PKSA to 17 % at 6 % PKSA. There is a slight decrease in the silt and clay fraction of the natural soil, which decreased from 51 % and 38.7 % to 46.0 % and 36.3 % at 4 % and 2 % PKSA content, respectively.

The reduction observed between the stabilizer and the soil particles may be as result of the agglomeration and flocculation of the clay particles and ion exchange at the surface of the clay particles; as the excess  $\text{Ca}^{2+}$  in the palm kernel shell Ash reacts with the lower valence metallic ions in the clay structure (Sani, 2009).



**Figure 4.4a; The Variation Palm Kernel Shell on Particle size distribution of black cotton soil in hydrometer analysis**



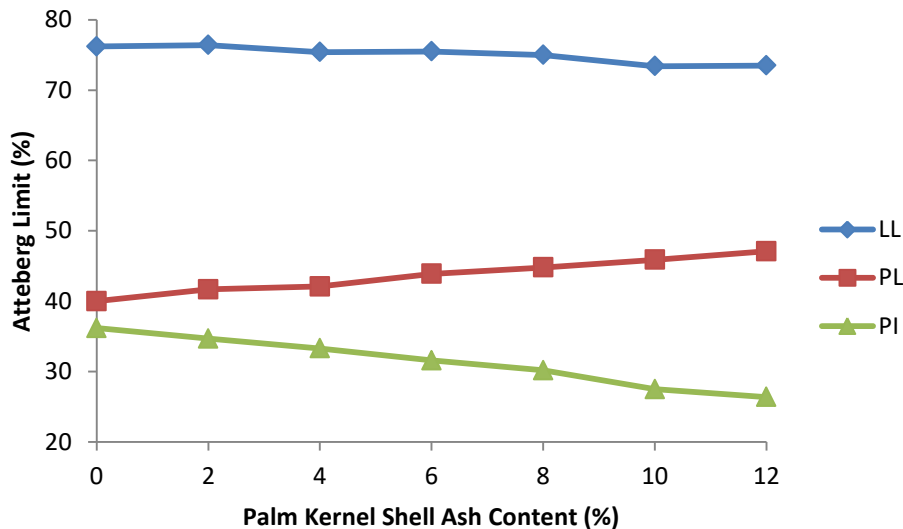
**Figure A4.4b: Variation of black cotton soil fraction with palm kernel shell ash content during hydrometer analysis**

#### 4.2.4 Atterberg limits

The effect of Palm Kernel Shell Ash (PKSA) content on the Atterberg limits (i.e., liquid limit, LL, plastic limit, PL and plasticity index, PI) are shown in Figure 4.5, The liquid limit and the plasticity index values decreased with increasing PKSA content while the plastic limit increases. This trend is similar to the findings reported by Mu'azu (2007) for black cotton soils.

The reduction in liquid limit with PKSA content may be as a result of the cation exchange reaction which flocculated the soil particles together and reduced the clay size fraction and hence increased the soil surface area (Muhammad and Yamusa, 2013). The detailed tests results are given in Table A4.5 in the Appendix.

The one – way analysis of variance (ANOVA) test on Atterberg limit results (i.e., liquid limit, plastic limit and plasticity index) shown in Table 4.5 indicate that the effect of palm kernel shell ash on black cotton soil is statistically significant ( $F_{CAL} > F_{CRIT}$ ).



**Figure 4.5: Variation of Atterberg limits of black cotton soil with palm kernel shell ash content**

**Table 4.5: One - way analysis of variance result for Atterberg limits of black cotton soil – palm kernel shell ash mixtures**

<b>Property</b>	<b>Source</b>	<b>Degree of Freedom</b>	<b>Fcal</b>	<b>P-value</b>	<b>F crit</b>	<b>Remarks</b>
<b>Moisture Content</b>	Liquid Limit	1	1792.793	1.3E-12	5.0	Significant effect
	Plastic Limit	1	450.5317	1.2E-09	5.0	Significant effect
	Plasticity Index	1	136.5818	3.74E-07	5.0	Significant effect

#### **4.2.5 Cation exchange capacity**

Some clay undergoes isomorphous substitution, that is, substitution of cation of one kind by another while retaining the same crystal structure (Azige, 2012). This substitution, along with the dissociation of hydroxyl ions, results in a residual negative charge on the surface of the clay mineral particles. Positively charged ions, (i.e., cations), are therefore adsorbed on its surface.

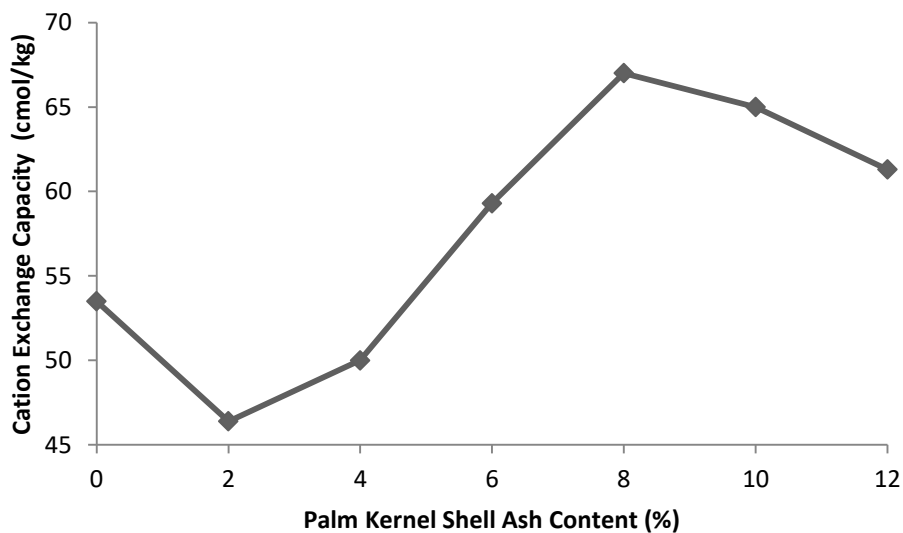
These ions are not strongly held and can be replaced by other ions present in water. This phenomenon is described as cation exchange. The quantity of exchangeable cation in a soil is termed exchange capacity Azige, (2012).

When water is added to soil particles, the negative charge on the surface of clay particles attracts the positive (hydrogen) charge ions of water molecules to form an adsorbed film of water.

This adsorbed film of water is thicker than the diameter of the particles (in the case of fine grained soil) which allows the movement of grains over one another Ovuvarume, (2011). This behaviour improved the plasticity of the soil as the soil can deform plastically without cracking when mixed with varying amounts of water. (Ovuvarume, 2011)

The effect of palm kernel shell ash on cation exchange capacity (CEC) of black cotton soil is shown in Fig. 4.6; The CEC values for black cotton soil and palm kernel shell ash are 53.5 and 57.0 cmol/kg, respectively. The CEC initially decrease from 53.5cmol/kg for natural to 46.4 cmol/kg at 2 % treatment thereafter increase to 67.0 cmol/kg at 8 % PKSA content and finally decreased to 61.3 cmol/kg at 12 % PKSA content.

Generally CEC increased with higher PKSA content as shown in Figure 4.6. The increase in CEC was as a result of decrease in the clay size fraction of the soil. The decrease in CEC of BCS could also be attributed to the reduction in pH of black cotton soil by palm kernel shell ash which has high potential to dissociate hydroxide ions from the water molecules (Warrick, 2002; Ochepe and Salahudeen, 2013). Detailed tests results are shown in Table A4.6 in the Appendix..



**Figure 4.6: Variation of cation exchange capacity of black cotton soil with palm kernel shell Ash content**

The one – way analysis of variance (ANOVA) test on the cation exchange capacity results shown in Table 4.6 indicate that the effect of palm kernel shell ash on black cotton soil is statistically significant ( $F_{CAL} > F_{CRIT}$ ).

**Table 4.6: The one – way analysis of variance (ANOVA) test on the cation exchange capacity of black cotton soil – palm kernel shell ash mixtures**

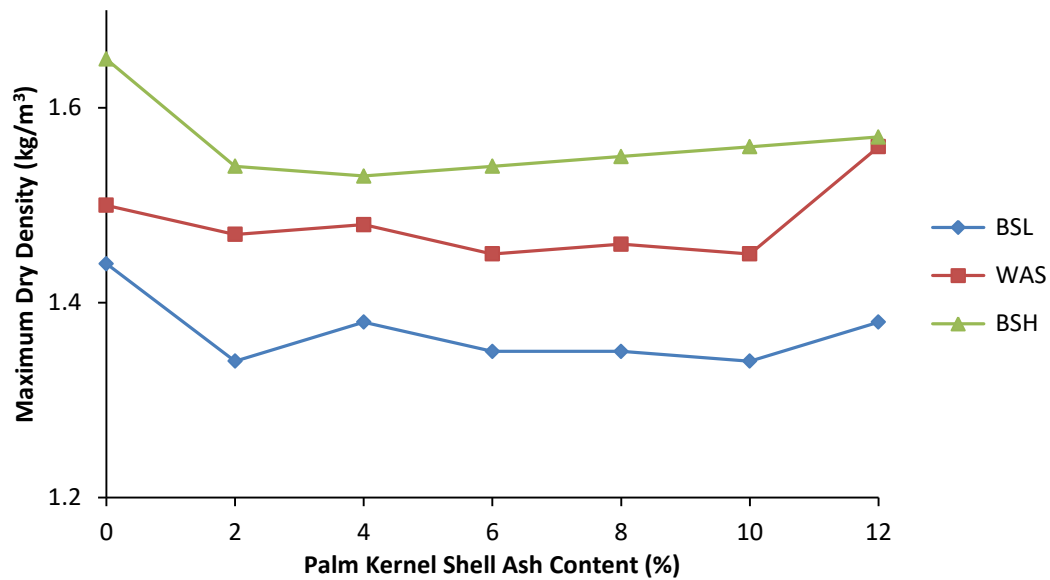
Property	Source of Variation	Degree of Freedom	$F_{Cal}$	P-value	$F_{Crit}$	Remarks
Cation Exchange Capacity	Palm Kernel Shell Ash	1	40.70	3.5E-05	4.75	There is Significant Effect

## 4.2.6 Compaction characteristics

### 4.2.6.1 Maximum dry density

The variation of maximum dry density (MDD) of black cotton soil with palm kernel shell ash content for the compactive efforts used in this study are shown in Figure 4.7. Generally, MDD values decreased with higher PKSA content and compactive effort.

For BSL compactive effort, the MDD value initially decreased from 1.44 Mg/m<sup>3</sup> for the natural black cotton soil to 1.34 Mg/m<sup>3</sup> at 2 % PKSA treatment and after picked up to 1.38 Mg/m<sup>3</sup> at 4 % PKSA and thereafter, gradually decreased to 1.34 Mg/m<sup>3</sup> at 10% PKSA and at higher percentage of the Ash content the MDD increased again to 1.38 Mg/m<sup>3</sup> at 12 % PKSA. The trend shows that MDD generally decreased with PKSA content.



**Figure 4.7: Variation of maximum dry density of black cotton soil with palm kernel shell ash content**

For the WAS compactive effort, the MDD initially decreased from a value of 1.50 Mg/m<sup>3</sup> for the natural soil to a 1.47 Mg/m<sup>3</sup> at 2 % and after increased to 1.48 Mg/m<sup>3</sup> at 4% palm kernel shell ash treatment and thereafter decreased with higher PKSA content to 1.45 Mg/m<sup>3</sup> at 10 % PKSA and at 12% PKSA the MDD increased to 1.56 Mg/m<sup>3</sup> which higher than that of the natural Soil.

For the BSH compactive effort, MDD decreased from an initial value of 1.65 Mg/m<sup>3</sup> for the natural soil to a value of 1.57 Mg/m<sup>3</sup> at 12 % PKSA content. This behaviour could partly be attributed to the flocculated and agglomerated clay particles occupying larger spaces leading to corresponding decrease in MDD (O’Flaherty 1988; Osinubi *et al.*, 2016).

Furthermore, the reduction in MDD with increases in palm kernel shell ash could also be due to the partial replacement of soil particles that are of higher specific gravity (2.34) in a given volume, by particles of palm kernel shell ash of comparatively lower specific gravity (1.57).

The increase in MDD at higher PKSA contents in all the compactive efforts could be because PKSA occupies most voids thereby increasing the density of soil. Detailed tests results are shown in Table A4.7a of the Appendix.

#### ***4.2.6.1.1 Regression Analysis for MDD***

Regression Analysis were performed on MDD, OMC, 7 days UCS, CBR and the index and other properties (PI, SG, CEC, F, CE and Ash) to know how reliable and dependable the results obtained are, hence the coefficient of the parameters in the model equation and ranking R determine the correlation between the dependent and independent variables.

where:

MDD = Maximum Dry Density

OMC = Optimum Moisture Content

UCS = Unconfined Compressive Strength

CBR = California Bearing Ratio

PI = Plasticity Index

SG = Specific Gravity

Ash = Palm Kernel Shell Ash

CEC = Cation Exchange Capacity

F = Percentage Finer

CE = Compactive Effort

**Model Equation for MDD**

$$MDD = -2.33 + 0.044*Ash + 0.056*PI + 0.23*SG + 0.002*CEC + 0.01*F - 0.000*OMC + 0.096*CE \tag{4.1}$$

Adjusted R<sup>2</sup> = 0.884 or 88.4%, hence R = 0.94 or 94%

From the model equation generated in equation (4.1), it is shown that specific gravity has greater influence on maximum dry density than plasticity index, the palm kernel shell ash and the fine particles content in the mixture. According to Smith (1986); if R > 0.8, this imply there is strong correlation between MDD and the variables.

From the obtained adjusted R<sup>2</sup> the parameters and the maximum dry density are strongly correlated. The detailed tests results are shown in Table A4.7 (b – c) in the Appendix.

**Table 4.7: One - way analysis of variance (ANOVA) test on the maximum dry density of black cotton soil – palm kernel shell ash mixtures**

Property	Source	Degree of Freedom	Fcal	P-value	F crit	Remarks
Maximum	BSL	1	13.6	0.004147	5.0	Significant effect
Dry	WAS	1	13.1	0.004732	5.0	Significant effect
Density	BSH	1	12.7	0.005105	5.0	Significant effect

The one – way analysis of variance (ANOVA) test on the MDD result for The three compactive efforts considered shown in Table 4.7 indicate that the effect of PKSA on black cotton soil is statistically significant (F<sub>CAL</sub> = 5.36 > F<sub>CRIT</sub> = 3.10)

#### 4.2.6.2 Optimum moisture content

The effect of palm kernel Shell ash content on optimum moisture content (OMC) of the Black Cotton Soil for BSL WAS and BSH compactive efforts are shown in Figure 4.8; and detailed result is shown in Table A4.8 (a and b).

Generally, OMC decreased with higher PKSA treatment but reduced with higher compactive effort. The decrease in OMC for the various compactive efforts used was solely due to the desiccation induced by the introduction of PKSA into the voids of the natural soil. These voids were originally occupied by both moisture and air.

With the introduction of PKSA into the soil, all the available water molecules were used up in the initial hydration reaction which consequently lowered the OMC values with increase in PKSA content, the demand for water by various cations and the clay minerals particles undergo hydration reaction, thus increasing the OMC (Majularani *et al* 2015). Another reason could be attributed to the increasing surface area caused by the higher amount of the PKSA (finer particles), which required more water for the lubrication of the entire material (Oyelakin, 2011)

The one – way analysis of variance (ANOVA) test on the OMC result in Table 4.8; showed that the effects of PKSA on black cotton soil is statistically significant ( $F_{CAL} = 115.215 > F_{CRIT} = 3.098$ ).

#### ***Model Equation for OMC***

$$OMC = 78.20 - 1.12 * Ash - 1.00 * PI + 1.28 * SG - 0.006 * CEC - 0.33 * F + 5.18 * MDD - 3.78 * CE \quad (4.2)$$

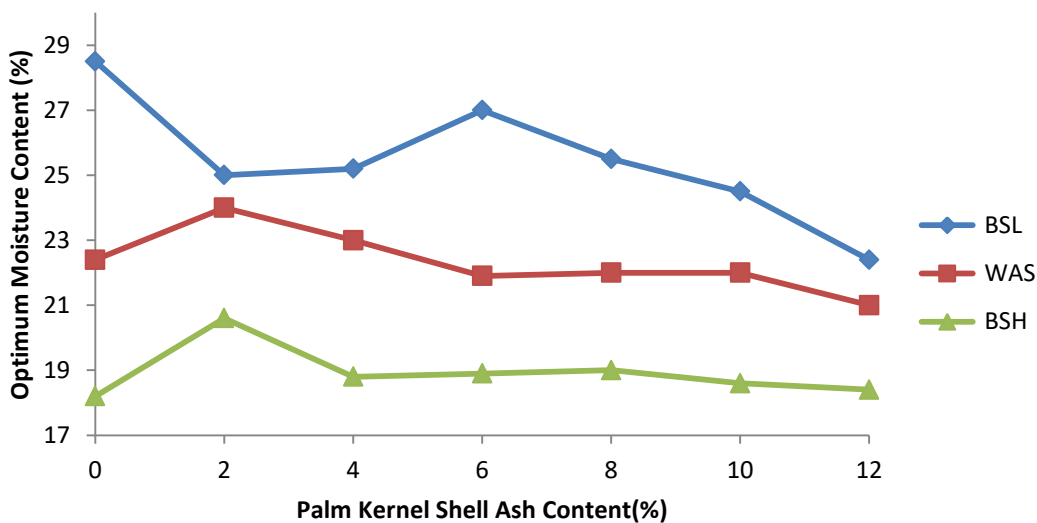
Adjusted  $R^2 = 0.848$  or 84.8%, therefore  $R = 0.92$  or 92%

The model generated in regression analysis shown in equation (4.2), shows that Optimum Moisture Content (OMC) is greatly influenced by the parameters, the most influential parameter

is Maximum Dry Density (MDD) followed by Compactive Effort (CE), Specific Gravity (SG), the Ash (PKSA), Plasticity Index (PI), the grain size (F) and Cation Exchange Capacity (CEC).

Adjusted  $R^2 > 0.8$  shows very strong correlation between optimum moisture content and the parameters.

The implication of the sign before the independent variables gives the direction of influence, the positive sign implies that as the independent variables increases the dependent variable increases and the negative sign implies that the increase in the independent variables will cause the decrease in dependent variable.



**Figure 4.8: Variation of optimum moisture content of black cotton soil with palm kernel shell ash content**

**Table 4.8: One - way ANOVA on the effect of PKSA on optimum Moisture Contents of BSL, WAS and BSH**

Property	Source	Degree of Freedom	Fcal	P-value	F crit	Remark
Optimum	BSL	1	118.7	7.2E-07	4.7	Significant Effect
Moisture	WAS	1	126.9	3.4E-06	5.3	Significant Effect
Content	BSH	1	59.6	1.6E-05	5.0	Significant Effect

#### 4.2.7 Unconfined compressive strength`

##### 4.2.7.1 7 days curing period

The effect of palm kernel shell ash (PKSA) on the unconfined compressive strength (UCS) of black cotton soil (BCS) cured for 7 days for the different compactive efforts considered is shown in Figure 4.9. Generally, UCS values increased from 119.54, 229.70 and 332.07 kN/m<sup>2</sup> for the natural soil to peak values of 419.36, 373.43 and 539.17 kN/m<sup>2</sup> at 8 % PKSA content for BSL, WAS and BSH energies, respectively.

Increase in strength for compactive efforts observed may be due to the release of calcium silicate hydrate (CSH) and calcium aluminate hydrate by PKSA, is responsible for the strength gain (Edeh et al 2012)

The one-way analysis of variance (ANOVA) test on the results of the effect of PKSA on UCS for the different compactive efforts after 7 days curing (see Table 4.9) shows that effect of PKSA on UCS of the soil is statistically significant because ( $F_{Cal} > F_{Crit}$ ).

##### 4.2.7.1.1 Model equation for UCS (7 days curing)

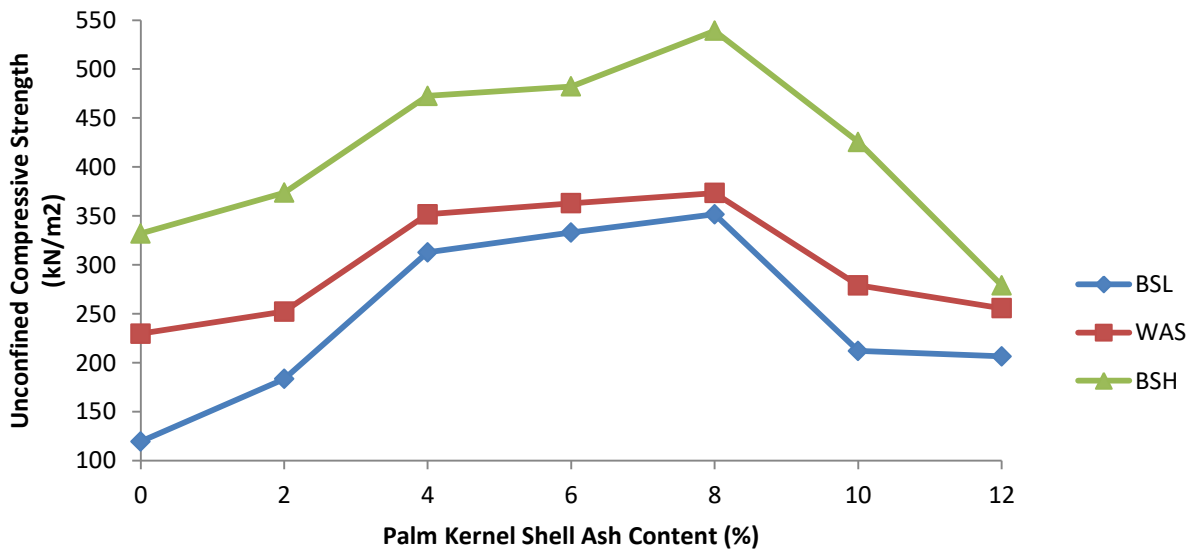
$$UCS_{7Days} = 1090.04 + 30.94 * Ash + 36.24 * PI - 1213.23 * SG + 8.09 * CEC + 7.49 * F - 7.10 * OMC - 215.98 * MDD + 82.52 * CE \quad (4.3)$$

Adjusted  $R^2 = 0.883$  or 88.3%, hence  $R = 0.9396$  or 94%

The model generated from regression analysis in equation (4.3) shows that unconfined compressive strength cured for 7 days was strongly influenced by parameters because  $R > 0.8$ .

Equation 4.3, shows that as the following parameters increases (i.e. the ash (PKSA) content, plasticity index (PI), cation exchange capacity (CEC) values the fine (F) content and compactive effort (CE)) the strength (UCS) increase.

Also observed, that specific gravity (SG), optimum moisture the strength content (OMC) and maximum dry density (MDD) causes decrease of the strength when they are increase and vice versa. The detailed tests results of the analysis are shown in Table A4.9 (a and b) in the Appendix



**Figure 4.9: Variation of unconfined compressive strength (7 days curing period) of black cotton soil with palm kernel shell ash content**

**Table 4.9: One - way analysis of variance (ANOVA) for unconfined compressive strength (7 days curing period) on black cotton soil – palm kernel shell ash mixtures**

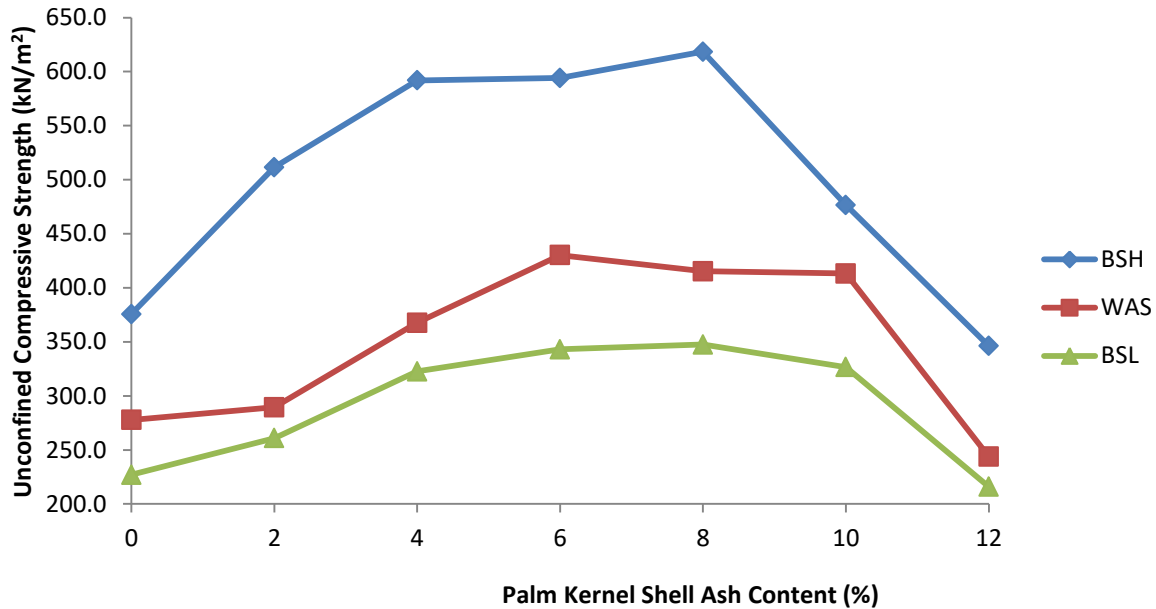
<b>Property</b>	<b>Source</b>	<b>Degree</b>	<b>F<sub>cal</sub></b>	<b>P-value</b>	<b>F<sub>crit</sub></b>	<b>Remarks</b>
	<b>of</b>	<b>of</b>				
	<b>Variation</b>	<b>Freedom</b>				
7 Days	BSL	1	52.52629	1.02E-05	4.75	Significant Effect
Cured	WAS	1	167.6168	2.07E-08	4.75	Significant Effect
UCS	BSH	1	165.4451	2.22E-08	4.75	Significant Effect

From the analysis result it is observed that palm kernel shell ash has significant effect on the 7days cured unconfined compressive strength as shown in Table 4.9 because  $F_{cal} > F_{crit}$

#### ***4.2.7.2 14 days curing period***

For 14 days curing period shown in Figure 4.10, UCS values generally increases with increase in PKSA content and compactive effort. The results recorded show that UCS values increased from 227.03, 277.76 and 375.57 kN/m<sup>2</sup> for the natural soil to 347.54 kN/m<sup>2</sup> at 8% PKSA treatment, 430.23 kN/m<sup>2</sup> at 6 % PKSA treatment and 618.46 kN/m<sup>2</sup> at 8 % PKSA treatment and compacted with BSL, WAS and BSH energies, respectively.

The one-way analysis of variance (ANOVA) test conducted on the effect of PKSA on UCS at the different compactive effort at 14 days curing Table 4.10, shows that , ( $F_{Cal} > F_{Crit}$ ) implies that PKSA has significant effect on the UCS of the BCS.



**Figure 4.10: Variation of unconfined compressive strength (14 days curing period) of black cotton soil with palm kernel shell ash content**

**Table 4.10: One - way analysis of variance (ANOVA) for unconfined compressive strength (14 days curing period) on black cotton soil – palm kernel shell ash mixtures**

Property	Source of Variation	Degree of Freedom	F <sub>cal</sub>	P-value	F <sub>crit</sub>	Remarks
14 Days Cured UCS	BSL	1	181.48	1.32E-08	4.75	Significant Effect
	WAS	1	139.38	5.8E-08	4.75	Significant Effect
	BSH	1	145.08	4.64E-08	4.75	Significant Effect

#### 4.2.7.3 28 days curing period

The result for 28 days curing period shown in Figure 4.11, UCS values increased with increase in PKSA content and compactive efforts. The results recorded show that UCS values increased from 257.85, 267.76 and 459.49 kN/m<sup>2</sup> for the natural soil to 407.68 kN/m<sup>2</sup> at 8% PKSA treatment, 678.31 kN/m<sup>2</sup> at 8 % PKSA treatment and 855.09 kN/m<sup>2</sup> at 8 % PKSA treatment and compacted with BSL, WAS and BSH energies, respectively.

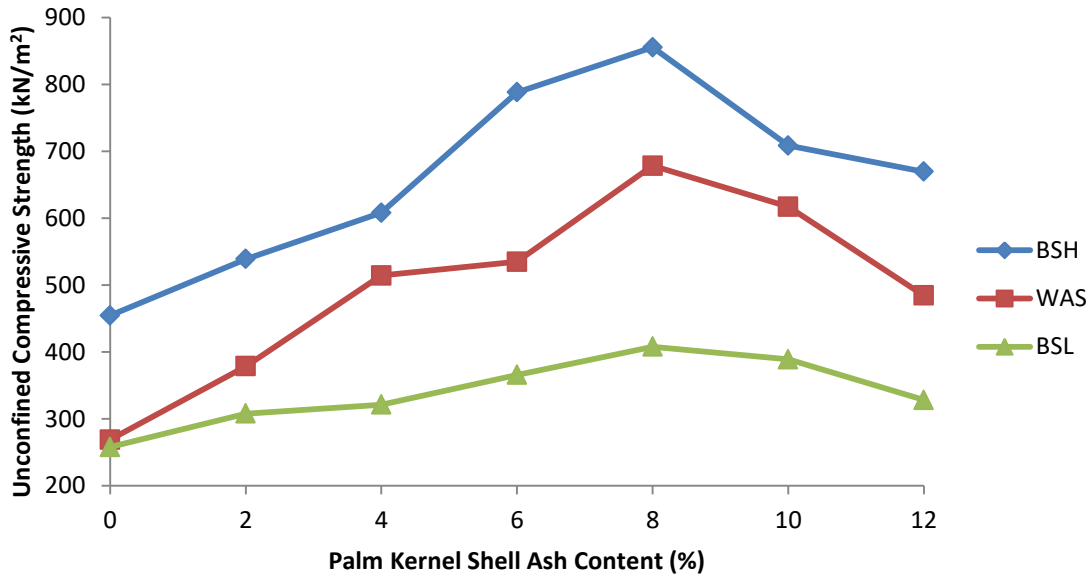
The variation of UCS of black cotton soil - palm kernel shell ash mixtures with curing period. Generally, UCS increased with curing period. The observed trend could probably be

attributed to the physico-chemical changes resulting from cation exchange reaction at the surface of the clay particles between the PKSA and clay particles (Osinubi *et al* 2016).

The attraction between the cations such as  $\text{Ca}^{2+}$  from the PKSA and the negatively charged ends of dipolar water molecules, which are in turn attracted by the negatively charged faces of the clay micro-structure, resulted in agglomeration and flocculation of the clay particles.

The reduction observed in UCS after peak values as shown in Figure 4.11 was probably due to the presence of excess lower valence ions that were not neutralized by the available higher valence cations. Similar results were reported by Osinubi *et al.* (2006; 2016) but locust beans waste and bagasse ashes were used respectively.

The one-way analysis of variance (ANOVA) test conducted on the effect of PKSA on UCS at the different compactive effort after 28 days curing Table 4.11, shows that , ( $F_{\text{Cal}} > F_{\text{Crit}}$ ) implies that PKSA has significant effect on the UCS of the BCS.



**Figure 4.11: Variation of unconfined compressive strength (28 days curing period) of black cotton soil with palm kernel shell ash content**

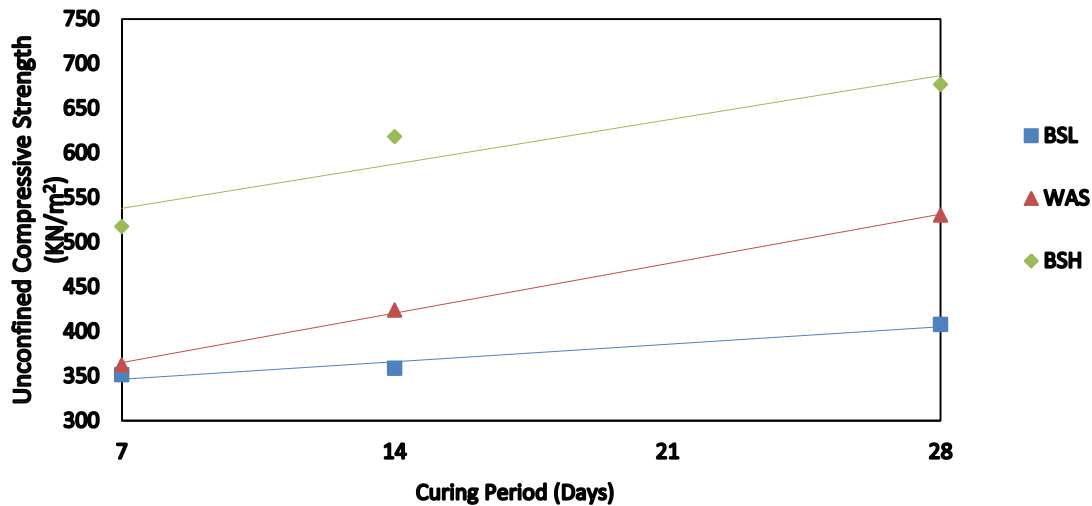
**Table 4.11: One - way analysis of variance (ANOVA) for unconfined compressive strength (28 days curing period) on black cotton soil – palm kernel shell ash mixtures**

Property	Source of Variation	Degree of Freedom	F <sub>cal</sub>	P-value	F <sub>crit</sub>	Remarks
28 Days Cured	BSL	1	299.1823	7.54E-10	4.75	Significant Effect
Unconfined	WAS	1	92.11916	5.57E-07	4.75	Significant Effect
Compressive Strength	BSH	1	154.1933	3.3E-08	4.75	Significant Effect

#### 4.2.8 Effect of curing period on unconfined compressive strength

From figure 4.12 it was observed UCS increases with curing period. The observed increases of UCS values could also be due to the formation of bonds between the clay mineral surface and the water molecules in the soil–PKSA mixture.

Furthermore, the increase in strength could be attributed to the presence of iron oxide (goethite) which dehydrates with time to yield higher strength (Nixon and Skipp, 1957; Little, 1967; Osinubi and Stephen, 2007; Osinubi *et al.*, 2016).



**Figure 4.12: Variation of peak unconfined compressive strength of black cotton soil - palm kernel shell ash mixture with curing period**

**Table 4.12: One - way analysis of variance (ANOVA) of the unconfined compressive strength of black cotton soil - palm kernel shell ash mixture**

Property	Source of Variation	Degree of Freedom	F <sub>cal</sub>	P-value	F <sub>crit</sub>	Remarks
Peak unconfined Compressive Strength	BSL	1	360.8797	4.52E-05	7.708647	Significant Effect
	WAS	1	73.40709	0.001019	7.708647	Significant Effect
	BSH	1	47.38154	0.002334	7.708647	Significant Effect

The one-way analysis of variance (ANOVA) test conducted on the effect of PKSA on peak UCS for different compactive effort at curing days in Table 4.12, shows that , ( $F_{Cal} > F_{Crit}$ ) implies that PKSA has significant effect on the peak UCS and curing days of the BCS.

#### 4.2.9 Durability

Durability investigation involves subjecting the soil samples to worst conditions that could be obtained in the field. It was evaluated by the immersion of specimens in water to determine resistance to loss in strength which is more acceptable for tropical regions like Nigeria Ola, (1974). The resistance to loss in strength was determined as the ratio of the unconfined compressive strength of specimen wax-cured for 7 days, de-waxed top and bottom to allow absorption of water and later immersed in water for 7 days to the UCS of specimens cured for 14 days.

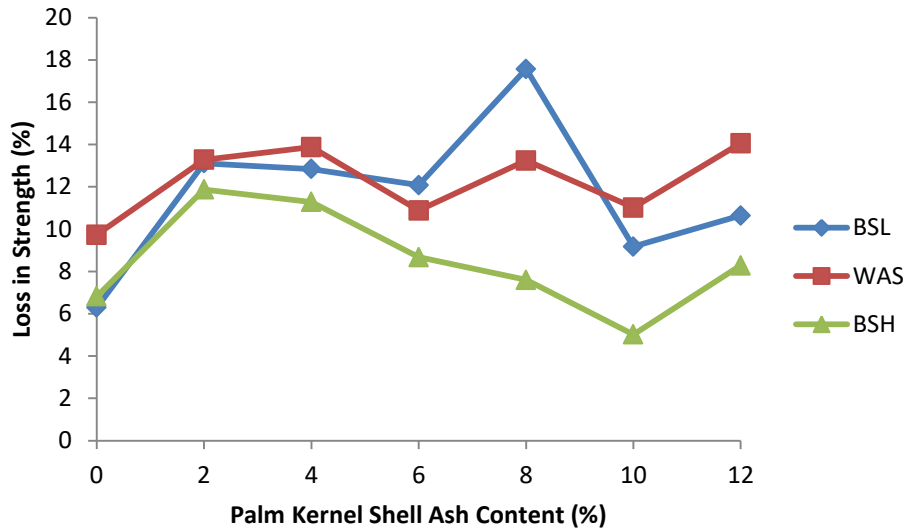
The effect of PKSA on resistance to loss in strength of the soil specimen for BSL, WAS and BSH compactions are shown in Figure 4.13. The resistance to loss in strength increased from 6.29, 9.73 and 6.81 % for the natural soils to peak resistance to loss in strength values of 17.6 % (i.e., 82.4 % loss in strength), 14.1 % (i.e., 85.9 % loss in strength) and 11.9 % (i.e., 88.1 % loss in strength) for specimens compacted with BSL, WAS and BSH energies, respectively.

The higher compactive efforts (i.e., WAS and BSH) recorded lower resistance to loss in strength values. The reason could be that the specimens compacted with BSL energy contained higher moisture and did not absorb much water when compared to the specimens compacted with WAS and BSH energies that had lower moisture contents and therefore absorbed more moisture that reduced their ability to resist loss in strength (Osinubi *et al* 2016).

The peak resistance to loss in strength values recorded for the compactive efforts considered are below the minimum 80 % resistance to loss in strength (i.e., maximum 20 % allowable loss in strength) for a 7 day curing dry and 4 day immersion period reported by Ola (1974) and Osinubi (2001a) regardless of the harshness 7 days immersion period was used in this study.

Based on the results obtained, regardless of the compactive effort used, the palm kernel shell ash treated black cotton soil did not meet the minimum durability requirement for use in pavement construction.

The one – way analysis of variance (ANOVA) test on the durability test results (see Table 9) , implied that the effects of PKSA on black cotton soil is statistically significant ( $F_{CAL} > F_{CRIT}$ ) for BSL and WAS while the result for BSH is statistically insignificant ( $F_{CAL} < F_{CRIT}$ ).



**Figure 4.13: Variation of resistance to loss in strength of black cotton soil with palm kernel shell ash content**

**Table 4.13: One - way analysis of variance (ANOVA) test on the durability of black cotton soil – palm kernel shell ash mixtures.**

Property	Source of Variation	Degree of Freedom	$F_{cal}$	P-value	$F_{crit}$	Remarks
Loss in Strength	BSL	1	7.24	0.01967	4.75	Significant effect
	WAS	1	12.85	0.003751	4.75	Significant effect
	BSH	1	1.99	0.183702	4.75	No significant effect

## 4.2.10 California Bearing Ratio

### 4.2.10.1 Unsoaked condition

The California bearing ratio (CBR) values of the untreated and treated black cotton soil generally increased with higher palm kernel shell ash content and compactive effort as shown in Figure 4.14. CBR values increased from 3, 8 and 11 % for the natural soil to 10 % at 10 % PKSA content, 15 % at 10 % PKSA content and 27 % at 10 % PKSA treatment when specimens were compacted with BSL, WAS and BSH energies, respectively.

The reason for the observed slight increases in CBR values could be due to inadequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) which is the major compound required for strength development. The Nigerian General Specification (1997) recommends that a CBR value of 180 % should be attained in the laboratory for cement stabilization. However, an unsoaked CBR value of 80 % is required for bases and soaked value of 30 % for sub-bases when both are compacted at optimum moisture and at 100 % West African Standard compaction (Gidigas and Dogbey 1980; Osinubi *et al.*, 2016).

The CBR values recorded for the palm kernel shell ash treated soil at the three compactive efforts are far below those prescribed in literature. This implies that palm kernel shell ash cannot be used as a single additive but can serve as an admixture when used with standard stabilizers. It is also important to note that CBR values significantly increased for specimens compacted with the BSL energy when compared to those of higher. Detail result in Table A4.14.

The one-way analysis of variance (ANOVA) test results of the effect of PKSA on CBR at the different compactive effort shown in Table 4.14 indicate that implies that PKSA has significant effect on the CBR of the specimens. ( $F_{Cal} > F_{Crit}$ )

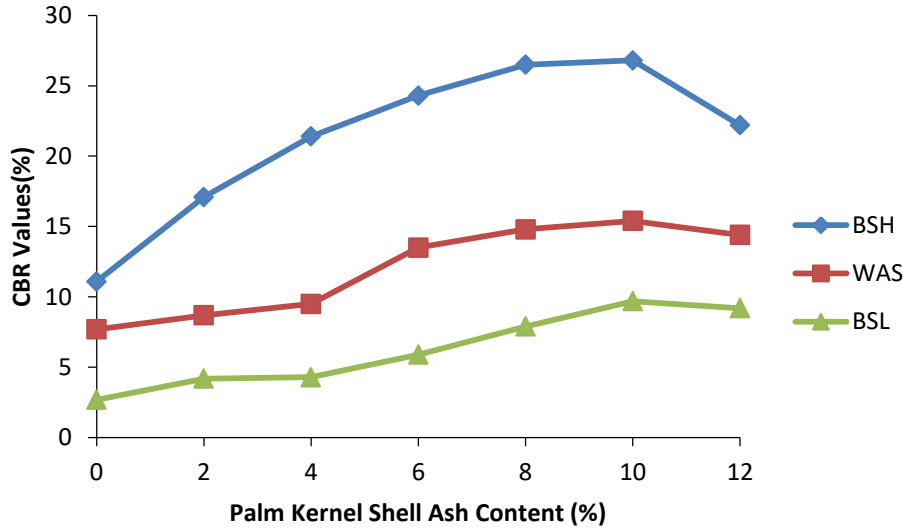
#### **4.2.10.1.1 Model equation for unsoaked CBR**

$$CBR_{unsoaked} = 60.3 + 0.4 * \% Ash - 0.3 * PI - 10.1 * SG + 0.2 * CEC + 0.2 * F + 0.3 * OMC - 34.6 * MDD + 11.7 * CE \quad (4.4)$$

$$R^2 = 0.923 \text{ or } R = 0.96$$

The result of regression analysis in equations 4.4 showed that the following parameters PKSA, CEC, OMC, the fine particles (F) and CE will increase the unsoaked CBR while the influence of other parameters (i.e. PI, SG and MDD) in the equation on the unsoaked CBR is inversely proportional.

Table A4.15 shows good fit when plotted because  $R > 0.8$  which implies that the parameters strongly influence the unsoaked CBR.



**Figure 4.14: Variation of Unsoaked California bearing ratio of black cotton soil with palm kernel shell ash content**

**Table 4.14: The one way analysis of variance (ANOVA) result of unsoaked CBR of black cotton soil – palm kernel shell ash mixtures**

Property	Source of Variation	Degree of Freedom	F	P-value	Fcrit	Remarks
<b>Unsoaked CBR</b>	BSL	1	0.020	0.890	4.75	No Significant effect
	WAS	1	8.646	0.012	4.75	Significant effect
	BSH	1	32.871	9E-05	4.75	Significant effect

#### 4.2.10.2 Soaked

The effect of palm kernel shell ash on CBR (soaked for 24 hours) of soil specimen for BSL, WAS and BSH compactive efforts are shown in Figure 4.15. The soaked CBR value increased with higher PKSA content for the three compactive efforts considered; the values for natural CBR (soaked) are 1%, 1% and 2% for BSL, WAS and BSH respectively, while peak

values of 3 % at 10% PKSA content, 3% at 10% PKSA contents and 7% at 10% PKSA contents was recorded for BSL, WAS and BSH compactive efforts.

The reduction with respect to the soaked CBR especially for the BSH values was due to the ingress of water into the specimen which weakened it and reduced its strength. The 7 % recorded for BSH being the highest does not meet the Nigerian General Specification (1997) requirement of 30 % for sub base materials.

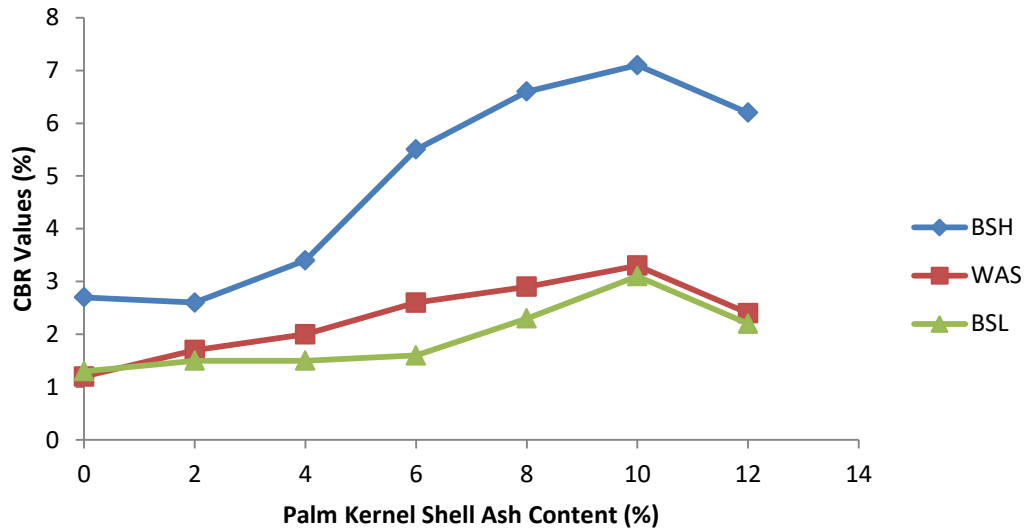
The two – way analysis of variance (ANOVA) test on the soaked CBR result for compactive efforts shown in Table 14a showed that the effects of PKSA on the soil specimen is statistically significant ( $F_{CAL} > F_{CRIT}$ ).

#### **4.2.10.2.1 Model equation for soaked CBR**

$$CBR_{Soaked} = 13.72 - 0.104*Ash - 0.287*PI - 1.878*SG + 0.096*CEC + 0.114*F + 0.121*OMC - 10.09*MDD + 2.85*CE \quad (4.5)$$

Adjusted  $R^2 = 0.687$  or 68.7%;  $R = 0.83$  or 83%

The model generated from regression analysis in equation (4.4) shows that soaked CBR was strongly influenced by the parameters, because  $R > 0.8$ . The most influential is maximum dry density followed by compactive effort next is specific gravity, plasticity index, optimum moisture content, fine content, the ash content and cation exchange capacity. It was also observed that the parameters with positive sign increase the CBR values when increase while the ones with negative sign will decrease the values of CBR when increased, The detailed results of the analysis are shown in Table A4.15 (a and b) in the Appendix.



**Figure 4.15: Variation of soaked California bearing ratio of black cotton soil with palm kernel shell ash content**

**Table 4.15: The one way analysis of variance (ANOVA) result on the soaked CBR of black cotton soil – palm kernel shell ash mixtures**

Property	Source of Variation	Degree of Freedom	$F_{cal}$	P Value	$F_{crit}$	Remarks
Soaked CBR	BSL	1	6.082903	0.029691	4.75	Significant effect
	WAS	1	4.994614	0.045213	4.75	Significant effect
	BSH	1	0.398752	0.539577	4.75	No Significant effect

## 4.2.11 Microanalysis

### 4.2.11.1 7 days curing period

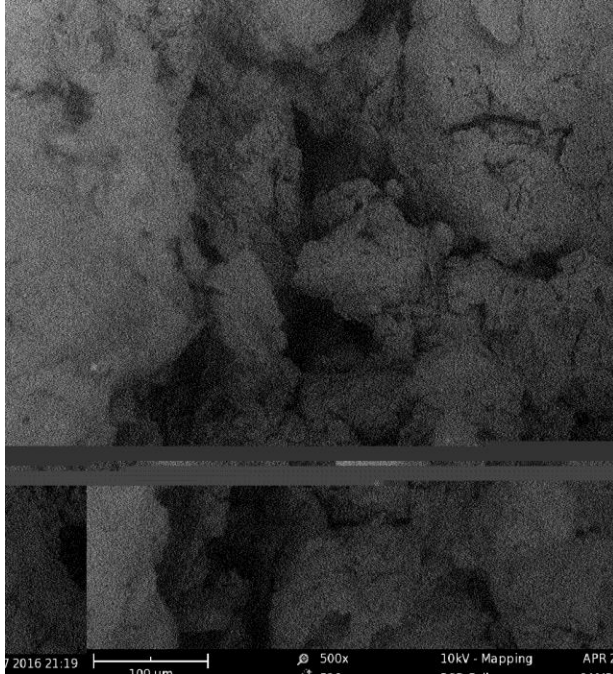
The results of microanalysis (using scanning electron microscope, SEM) of the natural soil specimen and treated soil (with 8% PKSA content) compacted with BSL energy and cured for 7 days are shown on Plates I and II. Micrographs of the specimens at x500 magnifications were considered.

The micrographs show the compactness of the soil particles. It was also observed that the natural soil has smooth and assemblage surfaces with spaces in between while the modified soil developed a smooth textured surface morphology. The explanation for this change in formation and morphology of the modified soil could be due to the reduction in the cohesiveness of the soil and the cation exchange reaction that occurred.

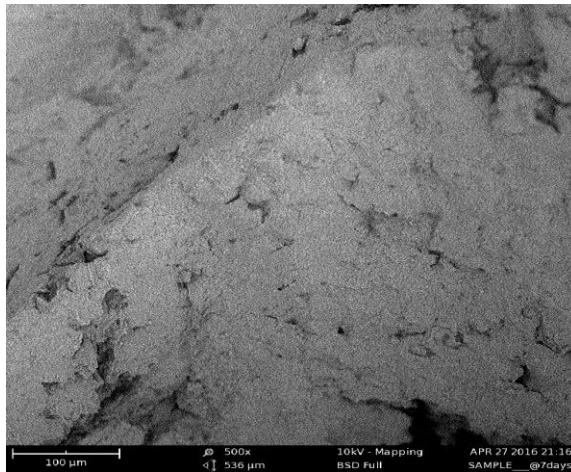
The more active and higher valent cations (i.e.,  $\text{Ca}^{2+}$ ) in the additives replaced the weakly bonded ions in the clay structure leading to the agglomeration and liberation of water bonded at the outer layers. Similar behaviour was reported by Ishola (2014). The decrease in cohesion may be due to the pozzolana reaction that resulted in the formation of calcium and alumina hydrate.

Mitchell (1956) and Mudgal *et al.* (2014) reported that the decrease in the cohesiveness is attributed to changes in the mineralogical composition and grain size distribution leading to the formation of a needle like morphology (rough textured surface). Changes in the quantities of chemical compounds such as carbonate, iron oxide, aluminium and silicon which precipitate at inter particle contact and act as cementing agent that caused the changes in the inter-particle and fabric orientation of the soil.

The decrease in the UCS and a change in the fabric orientation of the soil particle is an indication of improvement in the properties of the soil.



**Plate I: Micrograph of the natural black cotton soil cured for 7 days at magnification of x500 (BSL compaction)**



**Plate II: Micrograph of black cotton soil - 8% palm kernel shell ash mixture cured for 7 days with magnification of x500 (BSL compaction)**

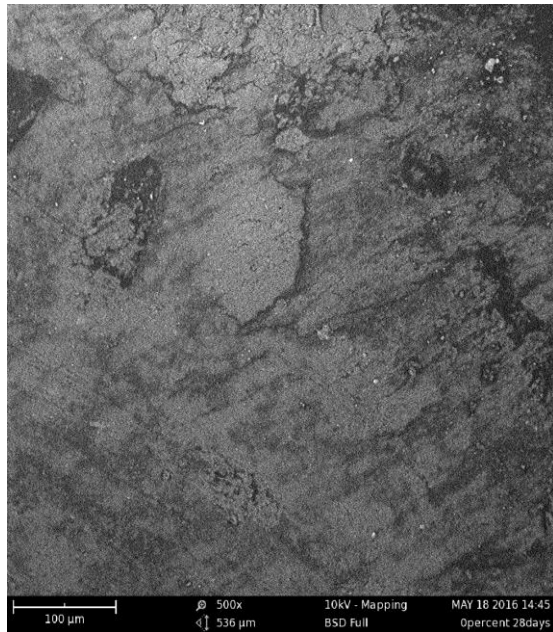
#### **4.2.11.2      28 days curing period**

The micrographs of the natural and treated soil compacted with BSL energy at 28 days curing period is shown on Plate III and IV. It was observed that the particle - structure arrangements appeared to be different from those of specimens cured for 7 days.

It was observed that specimens of the natural soil cured for 28 days had finely packed particle structure and modified has plate or flake-like surface morphology which indicates the presence of clay particles, hence larger particles are formed with increase in additives contents.

The flocculation of clays is caused by the attachment of negative particle at the surface to positive particle edge (i.e. electrostatic attractive forces), resulting in random particle orientation (Mitchell, 1956 and Mudgal *et al*, 2014). Hydration and ionic exchange could have led to the breaking of electrostatic and molecular bonds that resulted in the flocculent state with a reduction in the cohesiveness for both the natural and the modified soil after curing (see Plates III and IV).

Mitchel (1956) reported that the increase in the attractive forces over repulsion force with curing period suggest the flocculent nature of the soil. This also suggests the reduction in the pore spaces between the soil particles with increasing curing period. Mudgal *et al* (2014).



**Plate III: Micrograph of the natural black cotton soil cured for 28 days with magnification of x500 (BSL compaction)**



**Plate IV: Micrograph of black cotton soil - 8% palm kernel shell ash mixture cured for 28 days at magnification of x500 (BSL compaction)**

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

From the results of the preliminary investigations conducted on the natural soil, it is shown that the soil is fine-grained, with a natural moisture content of 26.75 %. The soil belongs to the CH group in the Unified Soil Classification System or A-7-5(20) soil group of the AASHTO soil classification system. According to NBRRI classification, the soil has low swell potential with low plasticity. About 89.7% of the soil particles passed BS No. 200 sieve (0.075µm aperture). The soil is greyish black in colour (from wet to dry states) with a liquid limit of 76.2 %, plastic limit of 40 % and plasticity index of 36.2%. The soil has a free swell of about 81.7%. Results of cation exchange reaction showed a trend of increase with higher palm kernel shell ash (PKSA) contents. Based on the results recorded in the study:

1. The liquid limit of the soil decreases from 76.2 to 73.4 % with increase in PKSA content. The plastic limit increased from 40 % to 47.1 % and the plasticity index decreased with higher PKSA content.
2. The maximum dry density (MDD) values increased with higher compaction energies. The natural soil recorded MDD values of 1.44, 1.50 and 1.65 Mg/m<sup>3</sup> for BSL, WAS and BSH compactions, respectively, decreased to 1.38, 1.45 and 1.57 Mg/m<sup>3</sup> at 12 %, 10 % and 12% treatment for BSL, WAS and BSH respectively. Optimum moisture content (OMC) values decreased with higher compactive effort. For the natural soil OMC values of 28.5, 22.4 and 18.2 % for BSL, WAS and BSH compactions, respectively, decreased to 22.4 and 21.0% at 12% treatment for the lower energy levels (i.e. BSL and WAS) and

for higher compaction energy, OMC increased to 20.6% at 2 % PKSA content thereafter decreased to 18.40 % at 12 % PKSA content.

3. The 7-day unconfined compressive strength (UCS) values increased with higher PKSA content and curing duration. For the natural soil UCS values of 119.54, 229.7 and 332.07 kN/m<sup>2</sup> increased to 351.59, 373.43 and 539.17 kN/m<sup>2</sup> at 8% PKSA content for BSL, WAS and BSH compaction, respectively..
4. The resistance to loss in strength of the soil increased from 6.29, 9.73, and 6.82% for the natural soil to peak values of 17.57, 13.24 and 7.60 % for BSL, WAS and BSH energies at 8 % PKSA, respectively. Only 82.43 % resistance to loss in strength (17.57 % loss in strength) at 8 % PKSA with BSL compaction met the limiting value of 80 % resistance to loss in strength based on 4 days soaking.
5. The unsoaked CBR values of 3, 8 and 11 % (for the natural soil) compacted with BSL, WAS and BSH energy levels, respectively, increased to 9, 15 and 27 % at 10 % PKSA treatment. The 24 hour soaked CBR values recorded peak values of 3, 3 and 7 % for with BSL, WAS, BSH compaction, respectively. The result showed that there was increase in the CBR value for BSL, WAS and BSH. On the other hand, the Unsoaked CBR values of 15 and 27 % with WAS and BSH compaction at 10 % PKSA treatments is suitable for use as subgrade material because it met the recommended value of 15 % for subgrade but does not meet the recommended value of 30 % for sub-base by the Nigerian General Specifications
6. Microanalysis conducted using scanning electron microscope showed a decrease in the cohesiveness and a change in the fabric orientation of the soil particle. Fibre metric

analysis conducted showed a reduction in pore volumes and pore area of the modified soil.

7. The one – way analysis variance test results showed that the treatment of black cotton soil with palm kernel shell ash had significant effect on the properties of the soil specimen even though the mixture did not meet the required specification for its use as a stand – alone stabilizer.
8. Based on the UCS value of 1710 kN/m<sup>2</sup> specified by TRRL for adequate cement stabilization the black cotton soil in this study treated with an optimal 8 % PKSA cannot be used as base material for road construction

## **5.2 Recommendation**

1. Based on the results obtained, 8 % palm kernel shell ash treatment of black cotton soil when compacted with West African Standard and British Standard Heavy energy levels is recommended for use as a sub-grade material in the construction of lightly trafficked roads.
2. It is suggested that PKSA should be used as an admixture in cement or lime stabilization of black cotton soil in road construction.

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## **APPENDIX**

**Table A3.1: Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specific Sizes**

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L (cm)	Actual Hydrometer Reading	Effective Depth, L (cm)	Actual Hydrometer Reading	Effective Depth, L (cm)
1.000	16.3	0	16.3	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5	36	10.4
1.006	14.7	6	15.3	37	10.2
1.007	14.4	7	15.2	38	10.1
1.008	14.2	8	15.0	39	9.9
1.009	13.9	9	14.8	40	9.7
1.010	13.7	10	14.7	41	9.6
1.011	13.4	11	14.5	42	9.4
1.012	13.1	12	14.3	43	9.2
1.013	12.9	13	14.2	44	9.1
1.014	12.6	14	14.0	45	8.9
1.015	12.3	15	13.8	46	8.8
1.016	12.1	16	13.7	47	8.6
1.017	11.8	17	13.5	48	8.4
1.018	11.5	18	13.3	49	8.3
1.019	11.3	19	13.2	50	8.1
1.020	11.0	20	13.0	51	7.9
1.021	10.7	21	12.9	52	7.8
1.022	10.5	22	12.7	53	7.6
1.023	10.2	23	12.5	54	7.4
1.024	10.0	24	12.4	55	7.3
1.025	9.7	25	12.2	56	7.1
1.026	9.4	26	12.0	57	7.0
1.027	9.2	27	11.9	58	6.8
1.028	8.9	28	11.7	59	6.6
1.029	8.6	29	11.5	60	6.5
1.030	8.4	30	11.4		
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				
1.039	5.9				

**Table A3.2: Values of k use in Equation for Computing Diameter of Particle in Hydrometer Analysis**

Temp	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	15.10	15.05	14.81	14.57	14.35	14.14	13.94	13.74	13.56
17	15.11	14.86	14.62	14.39	14.17	13.96	13.76	13.56	13.38
18	14.92	14.67	14.43	14.21	13.99	13.78	13.59	13.39	13.21
19	14.74	14.49	14.25	14.03	13.82	13.61	13.42	13.23	13.05
20	14.56	14.31	14.08	13.86	13.65	13.44	13.25	13.07	12.89
21	14.38	14.14	13.91	13.69	13.48	13.28	13.09	12.91	12.73
22	14.21	13.97	13.74	13.53	13.32	13.12	12.94	12.76	12.58
23	14.04	13.81	13.58	13.37	13.17	12.97	12.79	12.61	12.43
24	13.88	13.65	13.42	13.21	13.01	12.82	12.64	12.46	12.29
25	13.72	13.49	13.27	13.06	12.86	12.67	12.49	12.32	12.15
26	13.57	13.34	13.12	12.91	12.72	12.53	12.35	12.18	12.01
27	13.42	13.19	12.97	12.77	12.58	12.39	12.21	12.04	11.88
28	13.27	13.04	12.83	12.64	12.44	12.25	12.08	11.91	11.75
29	13.12	12.90	12.69	12.49	12.30	12.12	11.95	11.78	11.62
30	12.98	12.76	12.56	12.36	12.17	11.99	11.82	11.65	11.49

Source: Krishna Reddy, UI

Table A3.3: Temperature Correction Factors,  $C_T$ . Table A3.4: Correction Factors  $a$  for unit Weight of Solids,  $C_w$

Temperature °C	factor $C_T$
15	1.10
16	-0.90
17	-0.70
18	-0.50
19	-0.30
20	0.00
21	+0.20
22	+0.40
23	+0.70
24	+1.00
25	+1.30
26	+1.65
27	+2.00
28	+2.50
29	+3.05
30	+3.80

Unit Weight of Soil Solids, g/cm <sup>3</sup>	Correction factor $a$
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.04

Source: Krishna Reddy, UIC “Engineering Properties of Soils Based on Laboratory Testing” PP 52 – 54

**Table A4.2i: Effect of Palm Kernel Shell Ash on Specific Gravity of the Soil Specimen**

PKSA Content (%)	Specific Gravity
0	2.29
2	2.23
4	2.16
6	2.18
8	2.24
10	2.31
12	2.34

**Table A4.2 (ii): Specific Gravity of the Natural Soil**

<b>0% Treated Soil's SPECIFIC GRAVITY</b>			
Bottle No	R1	M	A0
Wt. of bottle + water full (W4)...g	43.00	50.40	48.80
Wt. of bottle + soil + water (W3)...g	48.80	56.10	54.20
wt. of bottle + soil (W2)...g	28.20	35.60	33.90
wt. of bottle (W1)...g	18.20	25.60	23.90
wt. of water (W4 - W1)...g	24.80	24.80	24.90
wt. of water added to soil (W3 - W2)...g	20.60	20.50	20.30
wt. of Soil (W2 - W1)...g	10.00	10.00	10.00
wt. of water displaced by the soil $W = (W4 - W1) - (W3 - W2)$ ...g	4.20	4.30	4.60
Specific Gravity $SG = (W2 - W1)/W$	2.38	2.33	2.17
Average Specific Gravity $SG_A = (SG1 + SG2 + SG3)/3$		<b>2.29</b>	

(iii)

<b>2% Treated Soil's SPECIFIC GRAVITY</b>			
Bottle No	M	R1	A0
wt. of bottle + water full (W4)...g	48.80	47.00	44.00
wt. of bottle + soil + water (W3)...g	55.10	53.10	49.70
wt. of bottle + soil (W2)...g	35.90	32.80	29.50
wt. of bottle (W1)...g	24.00	22.20	19.10
wt. of water (W4 - W1)...g	24.80	24.80	24.90
wt. of water added to soil (W3 - W2)...g	19.20	20.30	20.20
wt. of Soil (W2 - W1)...g	11.90	10.60	10.40
wt. of water displaced by the soil $W = (W4 - W1) - (W3 - W2)$ ...g	5.60	4.50	4.70
Specific Gravity $SG = (W2 - W1)/W$	2.13	2.36	2.21
Average Specific Gravity $SG_A = (SG1 + SG2 + SG3)/3$		<b>2.23</b>	

(iv)

<b>4% Treated Soil's SPECIFIC GRAVITY</b>			
Bottle No	R	B	Q
wt. of bottle + water full (W4)...g	46.30	44.30	41.60
wt. of bottle + soil + water (W3)...g	52.60	50.50	47.80
wt. of bottle + soil (W2)...g	32.80	31.40	28.00
wt. of bottle (W1)...g	21.40	19.30	16.60
wt. of water (W4 - W1)...g	24.90	25.00	25.00
wt. of water added to soil (W3 - W2)...g	19.80	19.10	19.80
wt. of Soil (W2 - W1)...g	11.40	12.10	11.40
wt. of water displaced by the soil $W = (W4 - W1) - (W3 - W2)$ ...g	5.10	5.90	5.20
Specific Gravity $SG = (W2 - W1)/W$	2.24	2.05	2.19
Average Specific Gravity $SG_A = (SG1 + SG2 + SG3)/3$		<b>2.16</b>	

(v)

<b>6% Treated Soil's SPECIFIC GRAVITY</b>			
Bottle No	5	2	6
wt. of bottle + water full (W4)...g	92.50	88.30	85.90
wt. of bottle + soil + water (W3)...g	99.10	94.80	92.30
wt. of bottle + soil (W2)...g	55.50	50.20	47.40
wt. of bottle (W1)...g	42.90	38.50	35.60
wt. of water (W4 - W1)...g	49.60	49.80	50.30
wt. of water added to soil (W3 - W2)...g	43.60	44.60	44.90
wt. of Soil (W2 - W1)...g	12.60	11.70	11.80
wt. of water displaced by the soil $W = (W4 - W1) - (W3 - W2)$ ...g	6.00	5.20	5.40
Specific Gravity $SG = (W2 - W1)/W$	2.10	2.25	2.19
Average Specific Gravity $SG_A = (SG1 + SG2 + SG3)/3$		<b>2.18</b>	

(vi)

<b>8% Treated Soil's SPECIFIC GRAVITY</b>			
Bottle No	7	1	8
wt. of bottle + water full (W4)...g	91.90	73.50	85.70
wt. of bottle + soil + water (W3)...g	98.70	80.30	92.40
wt. of bottle + soil (W2)...g	55.10	35.60	48.20
wt. of bottle (W1)...g	42.30	23.70	36.10
wt. of water (W4 - W1)...g	49.60	49.80	49.60
wt. of water added to soil (W3 - W2)...g	43.60	44.70	44.20
wt. of Soil (W2 - W1)...g	12.80	11.90	12.10
wt. of water displaced by the soil $W = (W4 - W1) - (W3 - W2)$ ...g	6.00	5.10	5.40
Specific Gravity $SG = (W2 - W1)/W$	2.13	2.33	2.24
Average Specific Gravity $SG_A = (SG1 + SG2 + SG3)/3$		<b>2.24</b>	

(vii)

<b>10% Treated Soil's SPECIFIC GRAVITY</b>			
Bottle No	R	B	7
wt. of bottle + water full (W4)...g	46.10	44.10	91.90
wt. of bottle + soil + water (W3)...g	53.10	51.10	98.80
wt. of bottle + soil (W2)...g	33.70	31.50	54.70
wt. of bottle (W1)...g	21.40	19.30	42.30
wt. of water (W4 - W1)...g	24.70	24.80	49.60
wt. of water added to soil (W3 - W2)...g	19.40	19.60	44.10
wt. of Soil (W2 - W1)...g	12.30	12.20	12.40
wt. of water displaced by the soil $W = (W4 - W1) - (W3 - W2)$ ...g	5.30	5.20	5.50
Specific Gravity $SG = (W2 - W1)/W$	2.32	2.35	2.25
Average Specific Gravity $SG_A = (SG1 + SG2 + SG3)/3$		<b>2.31</b>	

(viii)

<b>12% Treated Soil's SPECIFIC GRAVITY</b>			
Bottle No	7	1	8
wt. of bottle + water full (W4)...g	91.90	73.50	85.70
wt. of bottle + soil + water (W3)...g	99.10	80.70	92.80
wt. of bottle + soil (W2)...g	54.40	35.30	48.30
wt. of bottle (W1)...g	42.30	23.70	36.10
wt. of water (W4 - W1)...g	49.60	49.80	49.60
wt. of water added to soil (W3 - W2)...g	44.70	45.40	44.50
wt. of Soil (W2 - W1)...g	11.20	11.20	11.20
wt. of water displaced by the soil $W = (W4 - W1) - (W3 - W2)$ ...g	4.90	4.40	5.10
Specific Gravity $SG = (W2 - W1)/W$	2.29	2.55	2.20
Average Specific Gravity $SG_A = (SG1 + SG2 + SG3)/3$		<b>2.34</b>	

**Table A4.3a: The grain size distribution of treated black cotton soil mixed at optimum moisture content from British Standard Light compaction**

Sieve Size (mm)	Percentage Passing						
	0%PKSA	2%PKSA	4%PKSA	6%PKSA	8%PKSA	10%PKSA	12%PKSA
4.75	100	100	100	100	100	100	100
2.8	71.2	76.7	62.2	61.3	66.8	80.3	70
1.4	60.5	64.4	50.2	48.0	56.3	71.5	59.7
0.6	22.6	21.6	15.8	14.4	15.0	18.7	20.1
0.425	15.3	14.5	9.9	9.0	9.2	11.9	11.5
0.36	10.7	9.9	7.3	6.1	6.5	7.5	8
0.212	7.4	6.8	4.7	4.6	4.5	4.9	5.3
0.15	4.3	4.2	3.1	2.1	3.0	2.8	2.7
0.075	2.7	2.7	1.8	0.8	1.7	1.8	1.6

**Table A4.3b: The grain size distribution of treated black cotton soil at optimum moisture content of West African Standard compaction**

Sieve Size (mm)	Percentage Passing						
	0% PKSA	2% PKSA	4% PKSA	6% PKSA	8% PKSA	10% PKSA	12% PKSA
4.75	100	100	100	100	100	100	100
2.8	60.3	63.8	65.7	73.7	77.1	88.8	83.6
1.4	50.0	54.2	51.3	62.5	63.3	79.9	74.3
0.6	16.9	17.9	13.3	16.9	19.7	23.4	21
0.425	9.8	12.3	7.9	9.1	7.4	13.0	10.7
0.36	6.6	8.6	5.5	5.9	5.2	7.4	8.6
0.212	4.7	6.1	3.2	4.3	2.6	4.3	5
0.15	2.4	4.7	1.9	2.6	1.8	2.7	2.6
0.075	0.8	2.1	0.7	1.6	0.9	1.6	1.4

**Table A4.3c: The grain size distribution of treated black cotton soil at optimum moisture content of British Standard Heavy compaction**

Sieve Size (mm)	Percentage Passing						
	0% PKSA	2% PKSA	4% PKSA	6% PKSA	8% PKSA	10% PKSA	12% PKSA
4.75	100	100	100	100	100	100	100
2.8	70.0	62.4	71.9	84.7	86.7	94.0	89
1.4	58.3	51.9	60.0	76.2	77.8	88.2	78.5
0.6	18.8	15.7	15.9	25.3	27.6	32.5	28
0.425	11.6	9.4	10.3	15.1	14.0	16.1	19.3
0.36	7.0	6.2	6.9	9.5	8.9	8.2	7.8
0.212	4.8	3.8	4.2	5.9	5.1	5.1	6.5
0.15	2.4	2.4	3.0	3.6	2.9	3.3	4.2
0.075	1.1	1.0	1.6	2.3	1.8	2.0	2.4

**Table A4.4a: The variation of grain size distribution on black cotton soil in hydrometer analysis**

Sieve Size (mm)	Percentage Passing						
	0%	2%	4%	6%	8%	10%	12%
	PKSA	PKSA	PKSA	PKSA	PKSA	PKSA	PKSA
4.75	100	100	100	100	100	100	100
2.8	99.3	98.8	99.5	98.8	99.1	99.2	98.5
1.4	98.9	98.1	99.2	98.1	98.5	98.5	98.2
0.6	97.7	96.7	97.7	95.8	96.9	97.5	96.7
0.425	94.2	92.6	93.0	89.5	91.6	92.8	93.0
0.36	93.5	92.0	92.6	88.6	90.0	91.1	91.9
0.212	92.3	90.6	90.6	86.4	88.9	89.4	90.6
0.15	90.0	88.3	88.4	84.1	86.5	87.2	88.7
0.075	89.7	87.7	86.8	83.0	85.4	86.5	86.8
0.010	82.3	81.4	79.7	75.6	75.0	73.9	75.7
0.003	62.8	60.5	56.3	52.2	60.0	55.6	57.3
0.002	38.7	36.3	40.8	36.3	36.5	31.6	35.8
0.0015	17.2	15.4	26.8	24.2	16.3	13.2	24.8
0.0010	0.0	0.0	0.0	0.0	0.0	0.0	0.0

**Table A4.4b: The variation of Palm Kernel Shell Ash on soil group/texture of black cotton soil in hydrometer analysis**

<b>Range</b>	<b>4.75 - 0.075</b>	<b>0.075 - 0.002</b>	<b>0.002 - 0.001</b>	<b>Si + Cl</b>
<b>Ash %</b>	<b>Sand % (Sa)</b>	<b>Silt% (Si)</b>	<b>Clay % (Cl)</b>	<b>Fine % (F)</b>
0	10.3	51.0	38.7	89.7
2	12.3	51.4	36.3	87.7
4	13.2	46.0	40.8	86.8
6	17.0	46.6	36.4	83.0
8	14.6	47.9	35.7	83.6
10	13.5	54.9	31.6	86.5
12	13.2	51.0	35.8	86.8

**Table A4.5: The variation of PKSA on Atterberg Limit of Baure Black Cotton Soil**

<b>Ash (%)</b>	<b>LL (%)</b>	<b>PL (%)</b>	<b>PI (%)</b>
0	76.2	40	36.2
2	76.4	41.7	34.7
4	75.4	42.1	33.3
6	75.5	43.9	31.6
8	75.0	44.8	30.2
10	73.4	45.9	27.5
12	73.5	47.1	26.4

**TableA4.6: The effect of PKSA on Cation Exchange Capacity of the Baure Black Cotton Soil**

Ash Content (%)	CEC cmol/kg
0	53.5
2	46.4
4	50.0
6	59.3
8	67.0
10	65.0
12	61.3

**Table A4. 7a: The effect of Palm Kernel Shell Ash on Maximum Dry Density of the Baure Black Cotton Soil Compacted with BSL, WAS, and BSH**

% Ash	BSL (Mg/m <sup>3</sup> )	WAS (Mg/m <sup>3</sup> )	BSH (Mg/m <sup>3</sup> )
0	1.44	1.5	1.65
2	1.34	1.47	1.54
4	1.38	1.48	1.53
6	1.35	1.45	1.54
8	1.35	1.46	1.55
10	1.34	1.45	1.56
12	1.38	1.56	1.57

**Table A4.7b: Model parameters for MDD**

Source	Value	Standard error	t	Pr >  t	Lower bound (95%)	Upper bound (95%)
Intercept	-2.326	1.285	-1.810	0.083	-4.985	0.333
Ash	0.044	0.022	2.053	0.052	0.000	0.089
PI	0.056	0.025	2.214	0.037	0.004	0.108
SG	0.235	0.234	1.005	0.326	-0.249	0.718
CEC	0.002	0.002	0.970	0.342	-0.002	0.006
Fine (F)	0.013	0.008	1.705	0.102	-0.003	0.029
OMC	0.000	0.006	-0.006	0.995	-0.012	0.012
CE	0.096	0.021	4.694	0.000	0.054	0.139

**Table A4.7c: Goodness of fit statistics for MDD**

<b>Description</b>	<b>Value</b>
Observations	30.890
Sum of weights	30.890
DF	22.890
R <sup>2</sup>	0.911
Adjusted R <sup>2</sup>	0.884
MSE	0.001
RMSE	0.030
MAPE	1.487
DW	1.200
Cp	8.000
AIC	-209.727
SBC	-198.283
PC	0.151

**Table A4.8a: The variation of Palm Kernel Shell Ash on Optimum Moisture Content of the Baure Black Cotton Soil Compacted with BSL, WAS, and BSH**

Ash (%)	BSL (%)	WAS (%)	BSH (%)
0	28.5	22.4	18.2
2	25.0	24.0	20.6
4	25.2	23.0	18.8
6	27.0	21.9	18.9
8	25.5	22.0	19.0
10	24.5	22.0	18.6
12	22.4	21.0	18.4

**Table A4.8b: Model parameters for OMC**

Source	Value	Standard error	t	Pr >  t	Lower bound (95%)	Upper bound (95%)
Intercept	78.202	62.842	1.244	0.235	-57.559	213.964
Ash	-1.115	1.113	-1.002	0.335	-3.520	1.290
PI	-0.996	1.323	-0.753	0.465	-3.854	1.861
SG	1.277	11.178	0.114	0.911	-22.872	25.426
CEC	-0.006	0.090	-0.064	0.950	-0.200	0.188
Fine (F)	-0.326	0.386	-0.844	0.414	-1.159	0.508
MDD	5.178	10.292	0.503	0.623	-17.056	27.411
CE	-3.782	1.050	-3.602	0.003	-6.050	-1.514

**Table A4.8c: Parameters for Goodness of fit statistics for OMC**

<b>Description</b>	<b>Value</b>
Observations	21.000
Sum of weights	21.000
DF	13.000
R <sup>2</sup>	0.901
Adjusted R <sup>2</sup>	0.848
MSE	1.398
RMSE	1.183
MAPE	3.413
DW	2.032
Cp	8.000
AIC	12.971
SBC	21.327
PC	0.220

**Table A4.9a: The variation of Palm Kernel Shell Ash on Unconfined Compressive Strength of Baure Black Cotton Soil Compacted with BSL, WAS and BSH Energies and Cured for 7 Days**

Ash Content (%)	British Standard Heavy (BSH) KN/m <sup>2</sup>	West African Standard (WAS) KN/m <sup>2</sup>	British Standard Light (BSL) KN/m <sup>2</sup>
0	332.07	229.70	119.54
2	373.76	252.21	183.48
4	472.6	351.71	312.75
6	482.19	363.01	333.07
8	539.17	373.43	351.59
10	425.53	279.14	212.14
12	308.30	255.76	206.56

**Table A4.9b: Model parameters for 7Days UCS**

Source	Value	Standard error	t	Pr >  t	Lower bound (95%)	Upper bound (95%)
Intercept	1090.042	1993.379	0.547	0.595	-3253.157	5433.241
% Ash	30.945	34.304	0.902	0.385	-43.797	105.686
PI	36.241	40.295	0.899	0.386	-51.554	124.035
SG	-1213.233	342.453	-3.543	0.004	-1959.374	-467.092
CEC	8.086	2.746	2.944	0.012	2.102	14.070
Fine (F)	7.493	11.984	0.625	0.544	-18.618	33.604
OMC	-7.101	8.537	-0.832	0.422	-25.700	11.499
MDD	-215.983	310.057	-0.697	0.499	-891.539	459.573
EL	82.520	43.351	1.904	0.081	-11.934	176.974

**Table A4.9c: Goodness of fit statistics for 7Days cured UCS**

<b>Description</b>	<b>Values</b>
Observations	21.000
Sum of weights	21.000
DF	12.000
R <sup>2</sup>	0.930
Adjusted R <sup>2</sup>	0.883
MSE	1295.282
RMSE	35.990
MAPE	7.104
DW	1.483
Cp	9.000
AIC	156.744
SBC	166.145
PC	0.175

**Table A4.10: The variation of Palm Kernel Shell Ash on Unconfined Compressive Strength of Baure Black Cotton Soil Compacted with BSL, WAS and BSH Energies and Cured for 14 Days**

Ash Content %	British Standard Heavy (BSH) KN/m <sup>2</sup>	West African Standard (WAS) KN/m <sup>2</sup>	British Standard Light (BSL) KN/m <sup>2</sup>
0	375.57	277.76	227.03
2	511.52	289.53	260.86
4	591.77	367.62	322.67
6	594.07	430.23	343.11
8	618.46	415.29	347.54
10	476.61	413.26	326.69
12	346.13	243.66	215.95

**Table A4.11: The variation of Palm Kernel Shell Ash on Unconfined Compressive Strength of Baure Black Cotton Soil Compacted with BSL, WAS and BSH Energies and Cured for 28 Days**

Ash Content %	British Standard Heavy (BSH) KN/m <sup>2</sup>	West African Standard (WAS) KN/m <sup>2</sup>	British Standard Light (BSL) KN/m <sup>2</sup>
0	454.49	268.78	257.85
2	538.88	398.68	307.71
4	607.86	514.10	321.11
6	788.00	534.67	365.70
8	855.09	678.31	407.68
10	708.44	617.16	383.83
12	669.39	484.30	328.14

**Table A4.13: The variation of PKSA on resistance to loss in strength of the Soil Specimen**

Ash Content (%)	Resist to Loss in Strength (%)		
	(BSL)	(WAS)	(BSH)
0	6.29	9.73	6.82
2	13.11	13.28	11.87
4	12.84	13.88	11.28
6	12.08	10.88	8.67
8	17.57	13.24	7.60
10	9.17	11.02	5.69
12	10.64	14.06	8.28

**Table A4.14: The variation of Palm Kernel Shell Ash on Unsoaked CBR (at 2.54mm penetration) of Black Cotton Soil at three Compactive Efforts**

PKSA Content (%)	Unsoaked CBR Value at 2.54mm Penetration (%)		
	BSL	WAS	BSH
0	2.7	7.7	11.1
2	4.2	8.7	17.1
4	4.3	9.5	21.4
6	5.9	13.5	24.3
8	7.9	14.8	26.5
10	9.7	15.4	26.8
12	9.2	14.4	22.2

**Table A4.15: The variation of Palm Kernel Shell Ash on Soaked CBR (at 2.54mm penetration) of Black Cotton Soil at three Compactive Efforts**

<b>PKSA Content (%)</b>	<b>Soaked CBR Value at 2.54mm Penetration</b>		
	<b>BSL</b>	<b>WAS</b>	<b>BSH</b>
0	1.3	1.2	2.7
2	1.5	1.7	2.6
4	1.5	2	3.4
6	1.6	2.6	5.5
8	2.3	2.9	6.6
10	3.1	3.3	7.1
12	2.2	2.4	6.2